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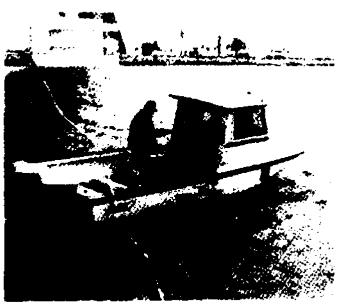
MISSISSIPPI-LOUISIANA ESTUARINE AREA STUDY:

SALINITY AND CIRCULATION AT AND NEAR BAY BOUDREAU IN BILOXI MARSHES EASTERN LOUISIANA



by

Walter Pankow, Julian M. Savage, Allen M. Teeter
William H. McAnally, Jr.

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

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The US Army Engineer District, New Orleans, has conducted a long-term study concerning the feasibility of diverting fresh water into the Lake Pontchartrain and Borgne basins in order to increase fish and wildlife productivity. This report describes a statistical analysis and a selected portion of the data acquired in the Bay Boudreau area by the US Army Engineer Waterways Experiment Station in support of the New Orleans District. The study approach, statistical analysis, spectral analysis and selected data are presented in this report.

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PREFACE

This report describes a statistical analysis and a selected portion of the data acquired in the Bay Boudreau area (Mississippi and Louisiana Estuarine Areas; Freshwater Diversion to Lake Pontchartrain Basin and Mississippi Sound) by the US Army Engineer Waterways Experiment Station (WES) for the US Army Engineer District, New Orleans (LMN). Mr. Burnell Thibodeaux, Engineering Division, LMN, was the project coordinator. The data acquisition and subsequent data analysis study were conducted by personnel of the Hydraulics Laboratory (HL) of WES under the general supervision of Mr. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; Mr. R. A. Sager, Assistant Chief of the Hydraulics Laboratory; Mr. W. H. McAnally, Jr., Chief of the Estuaries Division; and Mr. G. M. Fisackerly, Chief of the Estuarine Processes Branch. Work on this project began during March 1986, field data were collected between April 1986 and December 1987, and the analysis was completed during October 1988.

Mr. A. M. Teeter, Estuarine Processes Branch, was Project Engineer. The data collection program was designed by Mr. Teeter and Mr. H. A. Benson, Estuarine Processes Branch, with the advice and assistance of LMN. Mr. J. M. Savage, Estuarine Processes Branch, performed the statistical analysis and assisted in the preparation of this report. Ms. T. A. DeMoss, Information Technology Laboratory, WES, assisted in the application of the SAS (Statistical Analysis System) statistical software to the data analysis. This report, including the illustrations, was prepared by Mr. W. Pankow, Estuarine Processes Branch, and Appendix B was written by Mr. W. H. McAnally. Additional members of the field data acquisition team included Messrs. J. W. Parman, L. G. Caviness, S. E. Varnell, B. G. Moore, and Mmes. C. J. Coleman and L. A. Pace, all of the Estuarine Processes Branch. This report was edited by Ms. M. C. Gay, Information Technology Laboratory.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
Fahrenheit degrees	5/9*	Celsius degrees or Kelvins
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
yards	0.9144	metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

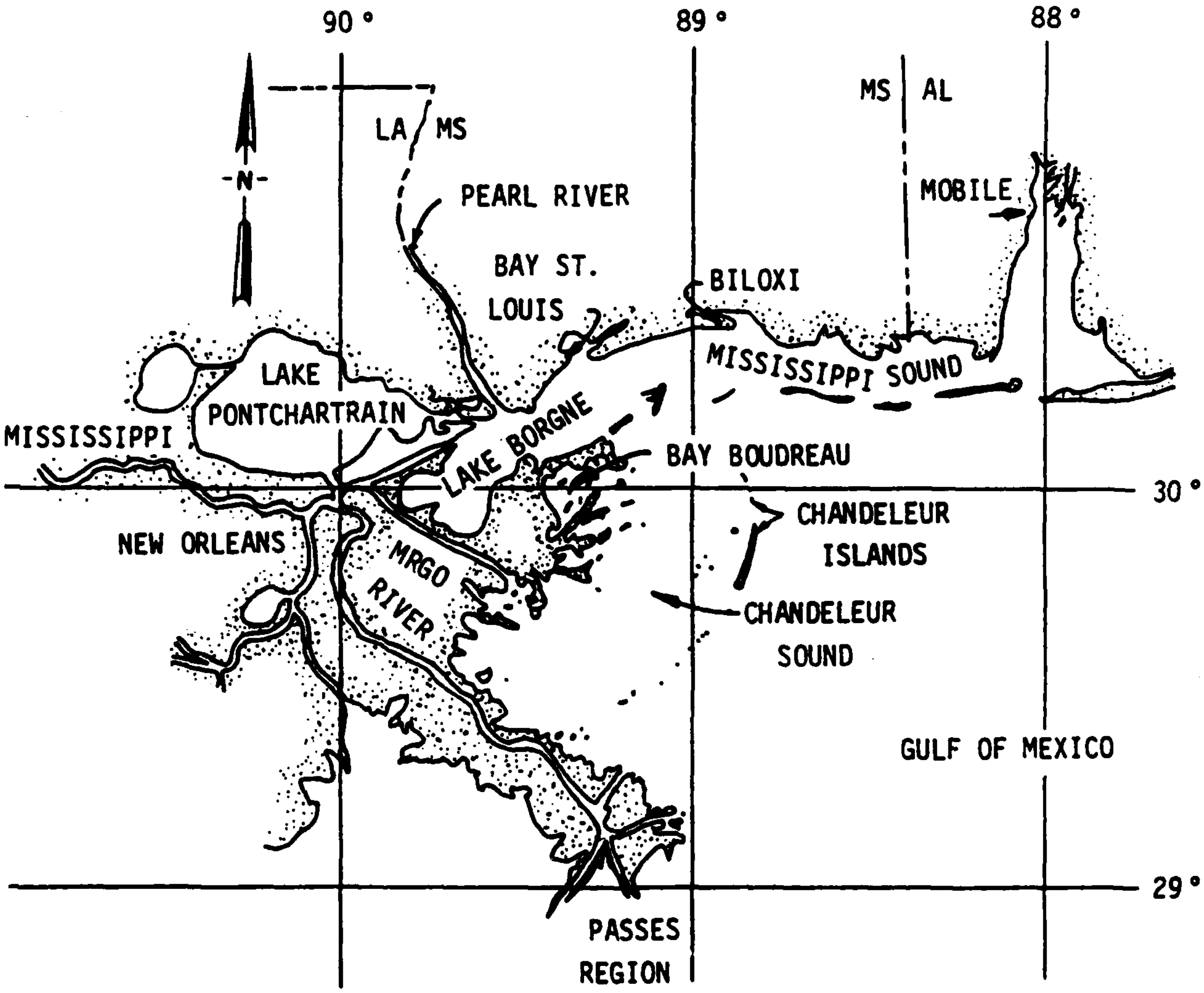

Figure 1. Location map

MISSISSIPPI-LOUISIANA ESTUARINE AREA STUDY

SALINITY AND CIRCULATION AT AND NEAR BAY BOUDREAU IN BILOXI MARSHES, EASTERN LOUISIANA

PART I: INTRODUCTION

Background

1. This report is part of a long-term study conducted by the US Army Engineer District (USAED), New Orleans, concerning the feasibility of diverting fresh water into Lakes Pontchartrain and Borgne basins from the Mississippi River to increase fish and wildlife productivity (Figure 1). The Mississippi and Louisiana estuarine areas have been estimated to include 2,960,000 acres* in southeastern Louisiana and southern Mississippi of which 65 percent of the total area is water with the majority of the remaining 35 percent being wetlands.** Consideration has been given to alternate plans and methods, costs, economic benefits, and environmental impacts (both negative and positive) that may result from this freshwater diversion. A key factor is the relationship between freshwater inflow and salinity levels.

2. Several different freshwater diversion scenarios were developed by the New Orleans District, and both a feasibility study report and Environmental Impact Statement were prepared. As a part of the feasibility report, "Freshwater Diversion to Lake Pontchartrain Basin and Mississippi Sound" (USAED, New Orleans, 1984), a regression analysis model was developed to relate salinity levels in Bay Boudreau with various freshwater inflows into the estuarine area.

3. During the feasibility study, the New Orleans District identified the maximum possible freshwater diversions through the proposed structure (based on water level difference between the Mississippi River and Lake Ponchartrain), and the optimal salinity conditions as shown in the following tabulation:

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* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 5.

** C. Wagahoff. 1983 (Sep). "Memorandum for Record, Mississippi and Louisiana Estuarine Areas Draft Feasibility Report - Review Conference," US Army Engineer District, New Orleans, New Orleans, LA.

Month	Maximum Possible Freshwater Diversion Q , cfs	Mean Optimal Salinity in Vicinity of Bay Boudreau, ppt
Jan	22,400	15-17
Feb	27,400	13-15
Mar	32,400	11-13
Apr	34,468	7-9
May	32,300	6-8
Jun	24,950	12-14
Jul	16,800	12.5-13.5
Aug	10,700	15-17
Sep	7,600	16-18
Oct	8,150	16-18
Nov	8.600	15-17
Dec	12,500	15.5-16.5

4. On 13 September 1983, an interagency conference was held to review the feasibility report. The study statistically related various freshwater inflows to salinity conditions at a site in the western area of the Biloxi Marsh known as Bay Boudreau. Concern was expressed at this conference about the effects of the relationship of freshwater flows and salinity conditions on the oyster beds. The New Orleans District requested that the US Army Engineer Waterways Experiment Station (WES) conduct further field sampling throughout the Mississippi-Louisiana estuarine area, but concentrate within the Bay Boudreau region, previously the most productive oyster region. To gain further understanding of salinity/freshwater inflow relationships and circulation patterns in the area, WES undertook a field data collection program to establish baseline conditions in the Bay Boudreau area with the purpose of developing a data base sufficient to refine the New Orleans District statistical model and support other studies.

Objective of the Work

5. The objectives of the work were as follows:

- a. To define seasonal and spatial salinity variations.
- b. To provide data for a baseline condition data base.
- c. To check and refine the previously developed regression relationship between freshwater supply and salinity in the area and calculation of required freshwater diversion rates.

Purpose of the Report

6. The purpose of this report is to present selected data and refinements to New Orleans District statistical modeling of salinity in the Bay Boudreau region. Comparison of the WES and the New Orleans District model results is also reported.

Scope of the Report

7. This report includes monthly average salinities and temperatures, average tidal currents, point samples for salinity, and statistical modeling of salinities in the Bay Boudreau and western Mississippi Sound areas based on freshwater inflows and precipitation. The report is not an overall data report nor a complete presentation of statistical and numerical treatments, but is an abbreviated report of the types of data that were collected, the statistical methods used, and the overall comparison results.

Site Conditions and Approach

8. Bay Boudreau is a large, shallow estuarine area that is centrally located near Chandeleur Sound (to the east), Mississippi Sound (to the north), and Lake Borgne (to the west) (Figure 1). In general, the tidal range is approximately 1 ft and the average depth is about 10 ft (National Oceanic and Atmospheric Administration (NOAA) 1985). Bay Boudreau is connected to the Mississippi River-Gulf Outlet (MRGO) by several access canals that provide additional circulation.

9. The overall approach was to monitor the area for over 1 year to observe seasonal variations, measure predetermined physical conditions, compile this information along with other hydrologic and meteorologic data obtained from other sources, and ultimately define the paths and relationships of the fresh and saline waters in the area. The Bay Boudreau area is highly permeable in that these wetlands contain virtually hundreds of canals and small saturated land masses. In order to provide meaningful results, the data gathering had to include numerous locations and be conducted during the seasonal fluctuations. The final acquisition program was designed to include four intensive seasonal surveys of approximately 1 week each and long-term

monitoring within the Lake Pontchartrain to Chandeleur Sound area (Figure 2). The intensive surveys collected data on currents and directions, conductivity, and temperature in the vertical water column at approximately 36 stations. During the August 1986 intensive survey, drogues were released and tracked in the area indicated in Figure 2. The long-term monitoring program collected data on water levels, conductivity, and temperature at eight locations.

10. Salinity distributions in estuarine areas depend in complex ways on a number of conditions. This may be especially true of the Mississippi-Louisiana estuarine area where tidal effects do not always dominate mixing and circulation. Precipitation and wind show considerable influence. A deterministic approach was considered for this study; however, it would have required much more time to develop and verify a numerical model. Stochastic approaches are not generally employed where average or normal conditions are the primary concern. The approach used by this study was empirical, and assumed a cause-and-effect dependence of salinities on some specified combination of parameters (e.g., precipitation, Pearl River flow, etc.). If multiple dependencies exist between parameters, it is possible that a high correlation between parameters might be found when, in fact, a third undetected parameter is responsible. Many parameters have similar seasonal variations that could

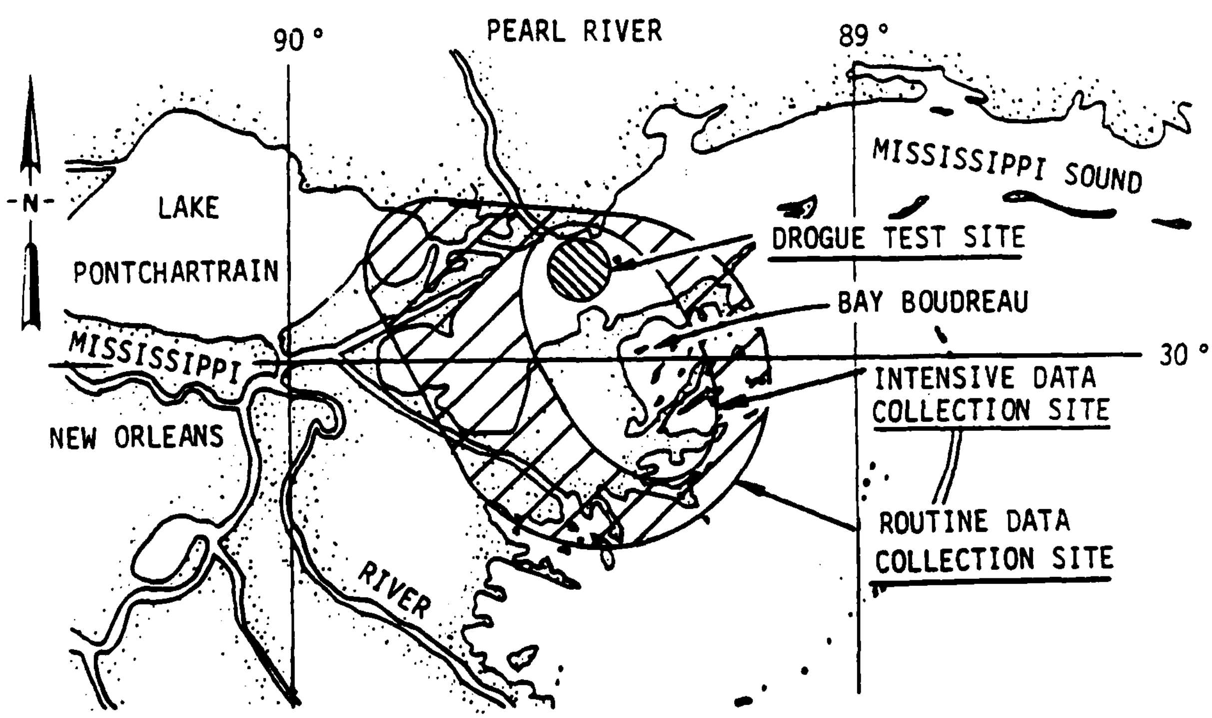


Figure 2. General locations of data gathering sites

mask true cause-and-effect relationships, causing the regression to be in error when conditions change. An additional potential source of error is that the system may respond differently to fresh water that is introduced in a different location than present natural flows. If this were to occur, it could also lead to misprediction by the regression. As long as these limitations are kept in mind, the regression results provide useful insight into selection of a structure design flow capacity.

PART II: FIELD INVESTIGATION AND DATA ACQUISITION

Long-Term Monitoring

11. Long-term monitoring stations were located along the MRGO (near Bayou a Loutre and Breton Sound), Bay Boudreau, St. Joe Point, Brush Island (north end), Lake Borgne (Proctor Point), and Lake Pontchartrain (Point Aux Herbes) (Figure 3). Eight locations that gave hourly temperature, conductivity, and tide data and thirty-six salinity locations that recorded monthly salinity data are shown in Figure 3. Figure 3 is a reduction of one of the 2-page data figures in Appendix A, but is shown here on one page for clarity. Eight Fischer and Porter water level recorders (tide gages) and Aanderraa RCM-4 recording meters (conductivity and temperature) were deployed. The Fischer and Porter meters were mounted on platforms and recorded (punched) on paper tape every 30 min. The Aanderraa meters were deployed and moored at middepth and recorded on magnetic tape every 30 min. All of the installed instrumentation was serviced at approximate 1-month intervals. A maximum of 36 stations were designated for monthly point salinity measurements between and beyond the long-term monitoring stations to better define both vertical and horizontal gradients. An InterOceans 513D Multiparameter Probe was used to obtain temperature and conductivity data at these locations. Samples were also taken at various depths and analyzed for salinity using a Beckman RS-7C or AGE model 2100 laboratory salinometer.

Intensive Survey Monitoring

12. The intensive survey deployments consisted of five arrays of current, conductivity, and temperature meters that were set to take measurements at middepth or at the surface and at the bottom. The four different season (see Table 1) intensive surveys consisted of taking hourly instrument readings for a 25-hour period. The fixed locations for this part of the survey were Bay Boudreau, between Bay Boudreau and St. Joe Point (two locations), Mississippi Sound, and Chandeleur Sound. Six moored velocity meter stations that recorded current, temperature, and conductivity are shown in Figure 4. In addition to the six stations, about 12 transect stations were located where current velocity and direction and a water sample were taken to later be

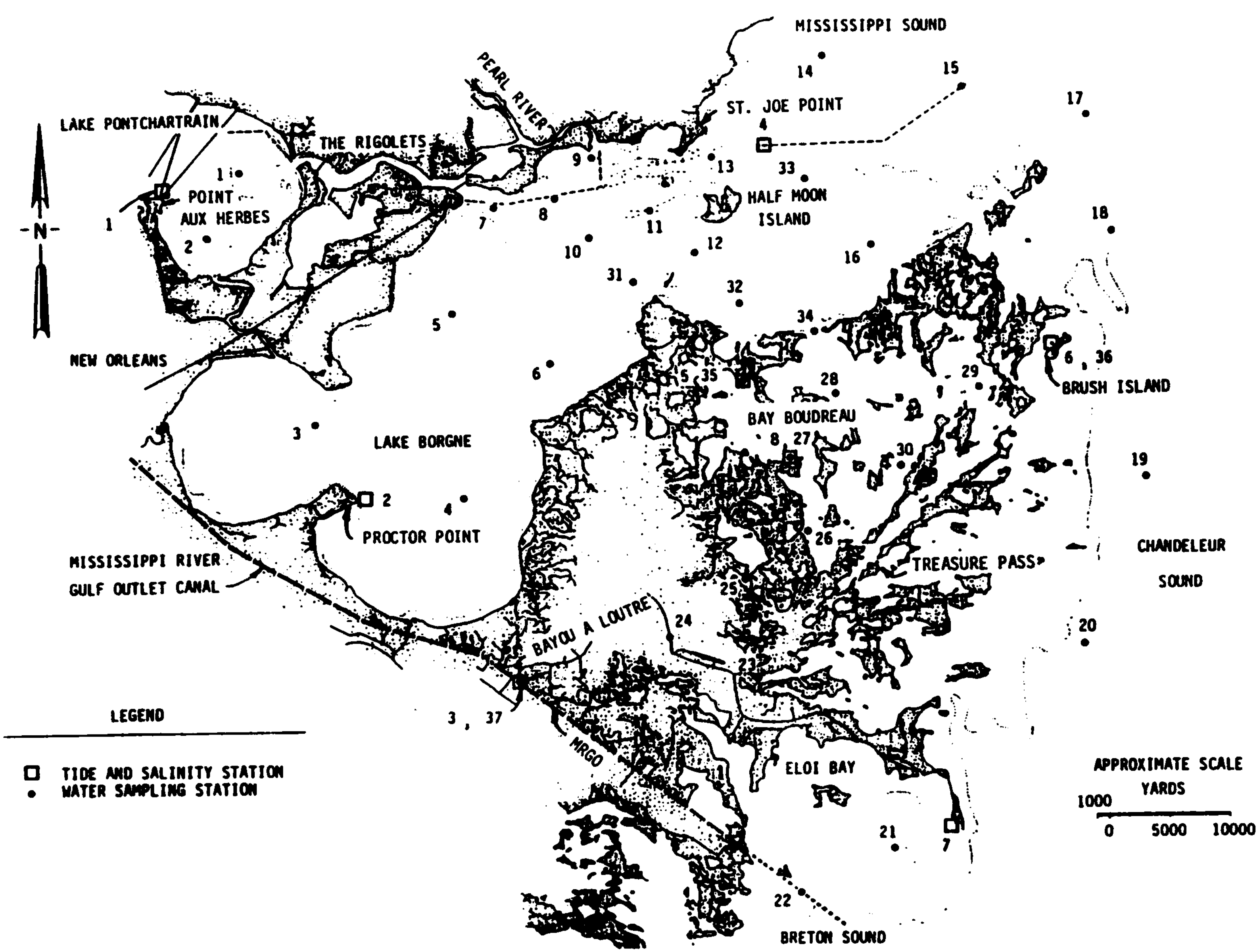


Figure 3. Locations of long-term sampling stations (see Appendix A for full size)

Table 1

Dates of Individual Surveys and Types of Data Acquired

Date	Intensive (I) or Long Term (L)	Salinity	Temperature	Current: Velocity	Current: Direction	Water-Surface Elevation
Initial installation of instrumentation and first survey 13 May 1986						
13 May 86	L	X	X			X
17-19, 24, 25 Jun 86	L	*	*	X	X	X
5-7, 13, 14 Aug 86	I	X	X	X	X	X
15, 22 Oct 86	I	X	X	X	X	X
18-19 Nov 86	L	X	X			
13-15 Dec 86	L	X	X			X
Jan 87	*	*	*	*	*	X
3-4, 10, 11 Feb 87	I	X	X	X	X	X
4-9 Apr 87	I	X	X	X	X	X
27-28 May 87	L	C	X			X
28, 29 Jul 87	L	Meter malfunctioned				X
12-13 Sep 87	L	X	X			X
17-19 Nov 87	L	X	X	*	*	X
Retrieval of instrumentation 26 Feb 88						

Note: Blank indicates no available data.
* No data taken due to bad weather.
C Conductivity measurements were taken in lieu of salinity.

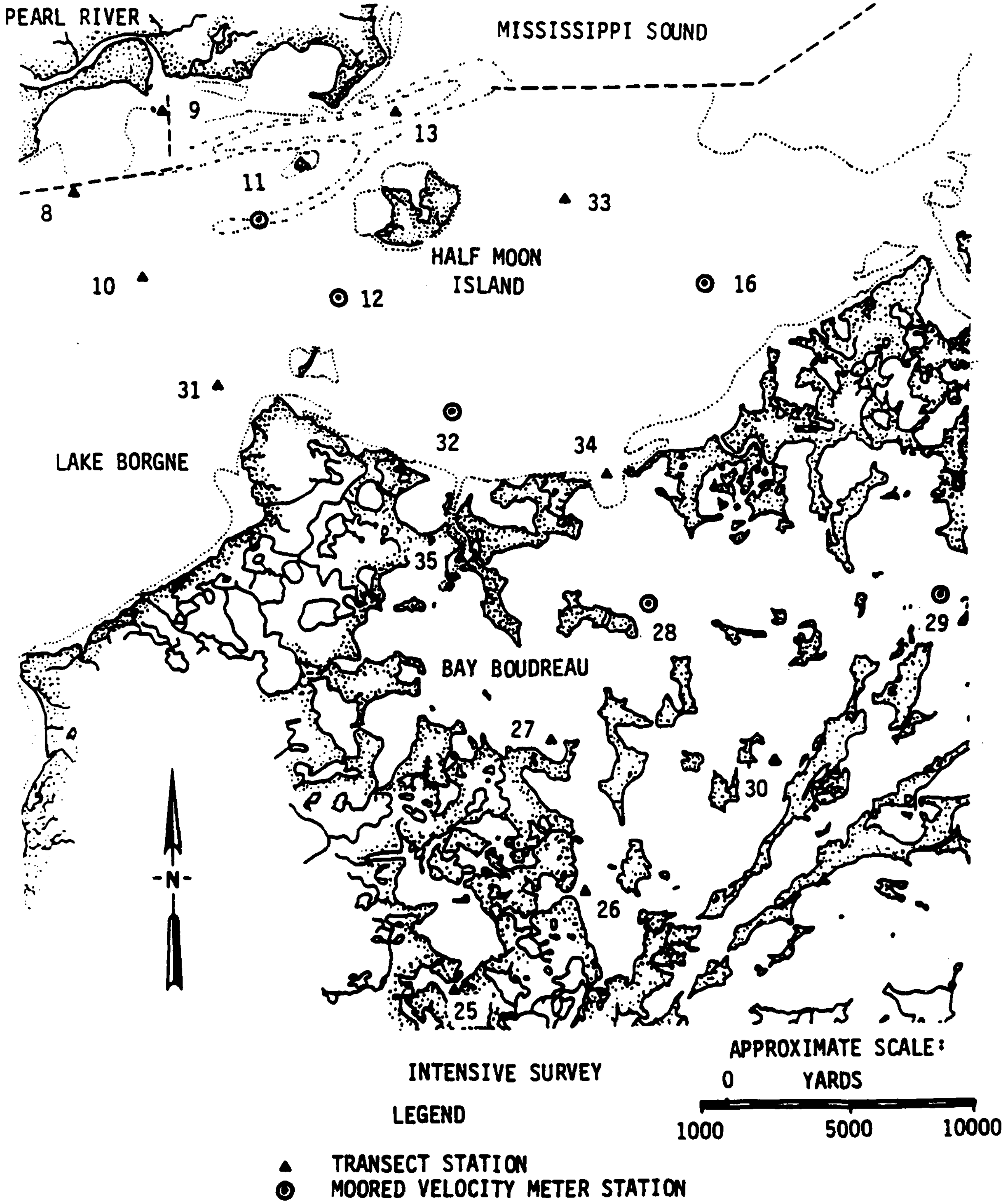


Figure 4. Locations of intensive survey sampling stations

analyzed for salinity are also shown in Figure 4. ENDECO Type 174 tethered current meters were used. During the intensive surveys, additional data were taken along transects between and extending beyond the fixed stations with an InterOceans 513D Multiparameter Probe. A total number of two survey boats with three crew members each were required for the intensive surveys.

Drogue Tests

13. During the August 1986 intensive survey, four different sets of drogues were launched and tracked during daylight hours. The "window shade" type drogues (Figure 5) were adjusted to follow the currents at an approximate depth of 2 ft. The bottom of the weighted nylon base was approximately 3 ft beneath the water surface, and the top of the pole was slightly more than 3 ft above the surface. The drogues were launched four at a time for ease of visual tracking and positioning with the Loran-C positioning system.

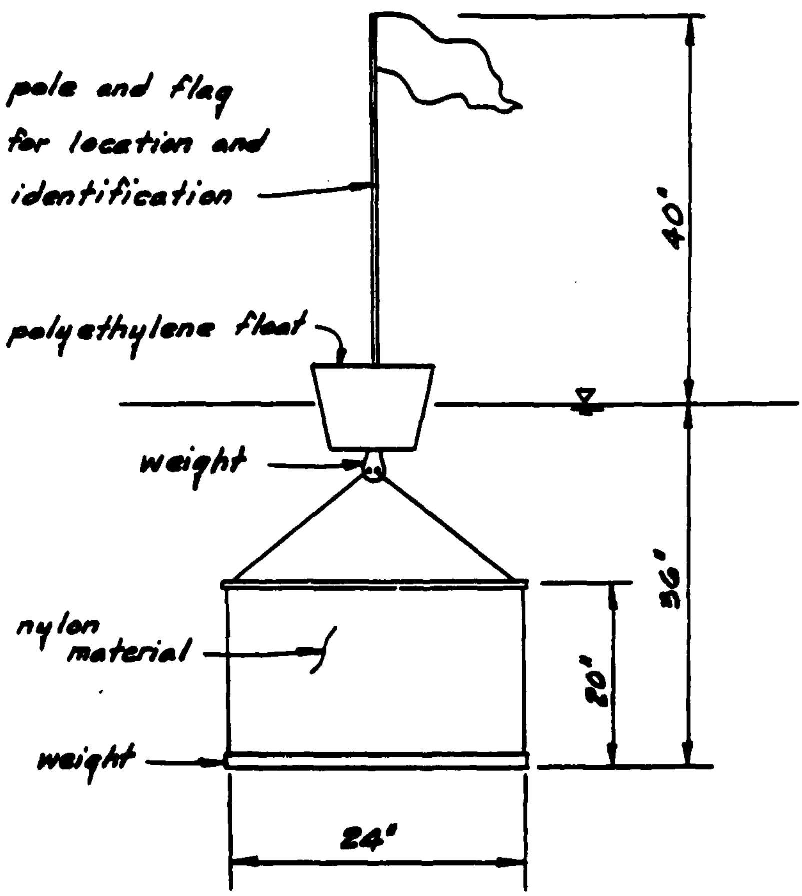


Figure 5. Window shade type drogues

Additional Data by Others

14. This location of the Louisiana and Mississippi coasts has been studied on previous occasions by others. Data were obtained from the New Orleans District, the US Geological Survey (USGS), the State of Louisiana Department of Wildlife and Fisheries, NOAA, and the US Fish and Wildlife Service (USF&WS), and will be discussed in subsequent sections.

Sample Analysis

15. Retrieved data, both water samples and tide gage tapes, were returned to WES for analysis. Water samples were tested for salinity content using standard laboratory procedures for conductivity and temperature. The tide tapes were read into a computer data file using the ENDECO Type 2501 Data Translator and tabulated for further analysis. Conductivity and temperature data tapes were read with an Aanderraa 2650 tape reader. Conductivity and temperature were used to calculate salinity using standard oceanographic methods as developed by Bennett (1976). Data taken onsite were cataloged, tabulated, and filed for future use. Between site visits, other standard operating procedures were followed, such as inspection of retrieved instruments, making calibration tests, and the cleaning of exterior covers of instruments. Other than the mention of the sample analyses and other standard operating procedures used in the field, these activities will not be described in this report.

Field Acquisition Procedures

16. The size of this data gathering effort becomes readily apparent when looking at the data plots. Because of the number of stations and the distance between, scheduling was critical so that one boat team would be able to safely cover the distances between assigned stations and collect the data within the 1-hr time limit during the intensive survey. Table 1 lists the dates of the individual surveys and the type of data acquired.

17. Specifically, the data acquisition program included the following:

- a. Water-surface elevation measurements at eight stations using platform-mounted tide gages that were left in place during the study.

b. Conductivity (salinity) and temperature measurements at these same eight stations, at surface or middepth and bottom. These meters were mounted on the same platforms as the tide gages but were submerged.

c. Current velocities and directions at 35 stations.

Instrumentation information can be found in Coleman et al. (1988).

18. During the course of this effort, a recurring problem was damage and/or loss of in situ equipment. Despite WES, New Orleans District, and US Coast Guard security, several of the meters and tide gages were either tampered with, damaged, or stolen. WES team members attempted to drag for the equipment after using Loran-C to locate the position; however, the equipment could not be located. Several meters have been listed as missing or damaged beyond repair. Tide Gages 4, 5, 6, and 7 were knocked out of service at various times throughout the course of this study. Two of the gages have never been recovered. Another problem was that of weather. On several occasions, storms with high winds caused wave conditions that were unsafe, and the data acquisition had to be abandoned. During one of the surveys, the weather and wind conditions were favorable for the formation of water spouts (Figure 6), and the boats were brought in for the protection of personnel.

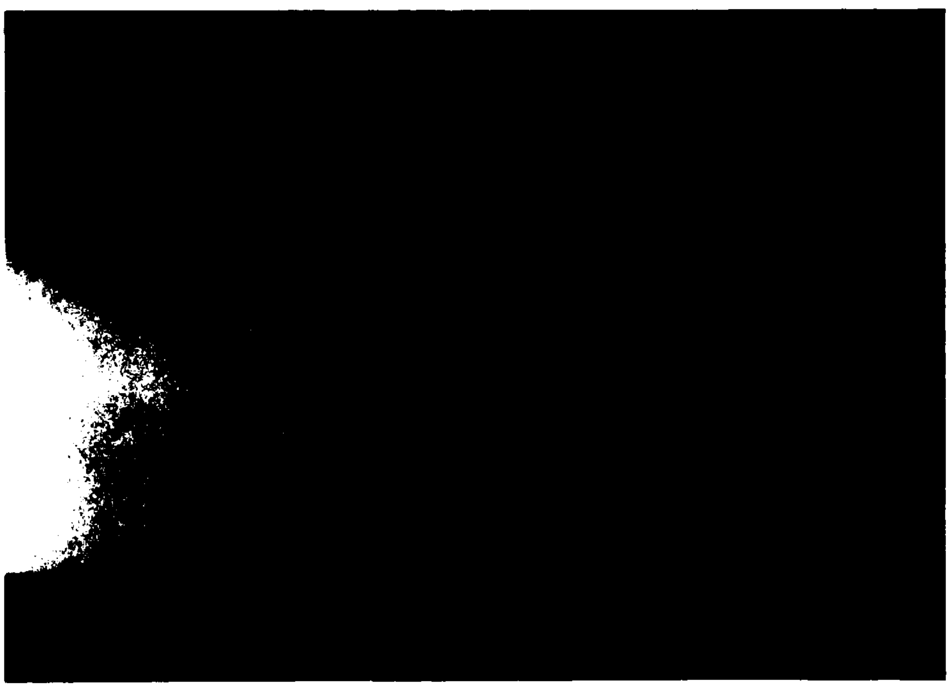


Figure 6. Formation of water spouts during the May 1986 survey

Description of Existing Data

19. One of the first actions at the beginning of this project was to locate available data and sources. The next step was to determine the relative usefulness and reliability of the data for this project. Historical records were desired to construct the normal or average quantity for the particular type of data in question. The year 1950 was arbitrarily chosen as the cutoff date. The type of existing data that was sought included salinity, temperature (air and water), wind (direction and speed), tides, freshwater inflow (rivers and tributaries), and precipitation. Because much of this area is remote, very little data from the site were located. However, various records have been maintained by several Federal agencies for surrounding areas from which data could be extrapolated. The following is a list of the data sources and the type of data that was used in conjunction with the prototype data acquired by the Hydraulics Laboratory:

- a. New Orleans District: the feasibility study (USAED, New Orleans, 1984).
- b. US Department of Interior, Geological Survey, Water Resources Division: 1985-1986 and 1986-1987 discharges for the Pearl River (Bogalusa, LA), Amite River (Denham Springs, LA), Tangipahoa River (Robert, LA), Tickfaw River (Holden, LA), Tchefuncta River (Folsom, LA), Natalbany River (Baptist, LA), all of which are unpublished data in the form of computer printouts.
- c. USF&WS: salinities for three locations in and near Bay Boudreau. The data are also unpublished and in the form of computer printouts.
- d. NOAA: air temperature, wind speed and direction, precipitation, and tide information. These data have been published in several NOAA publications (NOAA 1985, 1986a, 1986b, 1986c, 1986d, 1987a, 1987b, 1987c).

20. To comprehend the typical climatological trends more completely, the various records were compiled and plotted. Figure 7 depicts the monthly averaged trends covering the 29-year period 1951-1980 including wind, temperature, and precipitation. Climatological data for the years 1985 through 1987 are plotted in Figures 8-10, respectively. There is a notable difference in the 1951-1980 curves compared to this more recent period, but because of inherent smoothing in long-term data averages, peaks in the 1951-1980 period would tend to be smoothed that would be present in the shorter period.

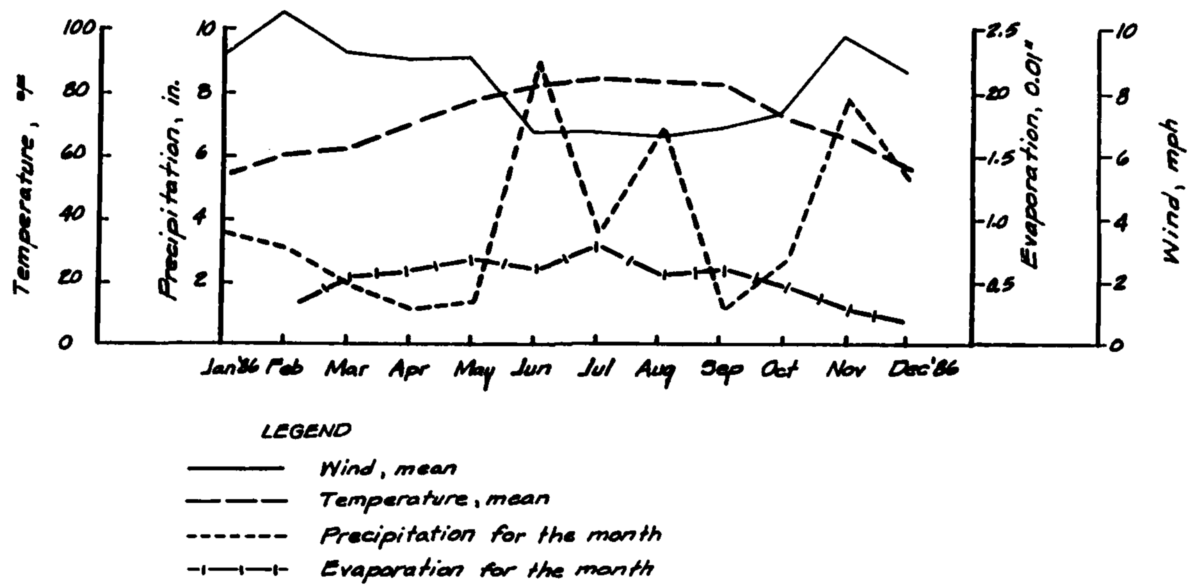


Figure 9. Climatological data for 1986

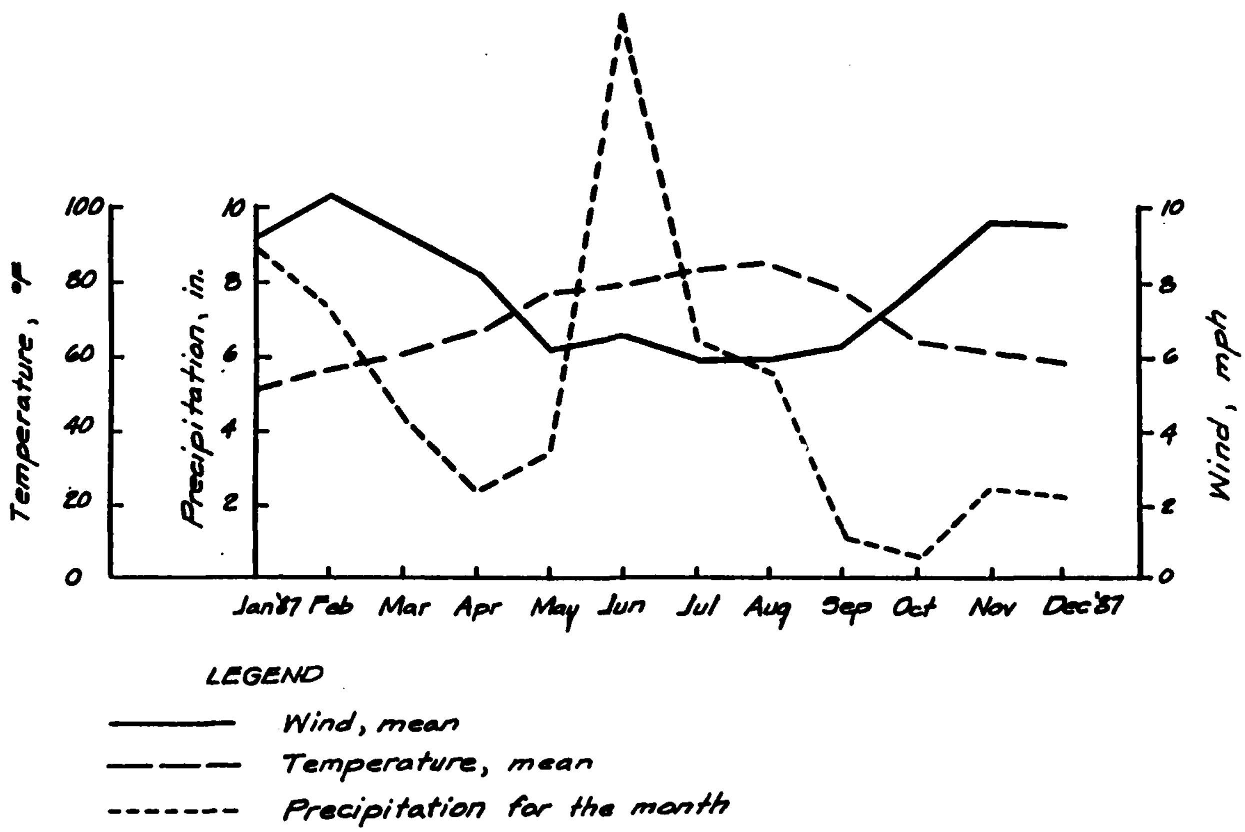


Figure 10. Climatological data for 1987

Comparison of Data Periods

21. The New Orleans District regression model was based on salinity data from Treasure Pass for 21 selected months from 1971 to 1978. Those data were compared to the WES-collected data of 1986-1987 to determine if the data were stationary. Salinity values according to flow are plotted in Figure 11. This figure compares salinity obtained by WES and the New Orleans District to Lake Pontchartrain and Pearl River flows. WES data at stations 5 and 8 were multiplied by a factor of 1.43 to equate them to New Orleans District data at Treasure Pass (1.43 is the average ratio of salinities at the two locations). Figure 12 compares the ratio of the Pearl River flow and Lake Pontchartrain flow to the total flow used by WES and the New Orleans District. These two figures show that for the same simple sum of Lake Pontchartrain and Pearl River flows, the salinity response is similar, but the longer term New Orleans District data set exhibited a much wider range of relative flows than the WES data set. Differences in regression results between the two data sets can be attributed to the latter observation.

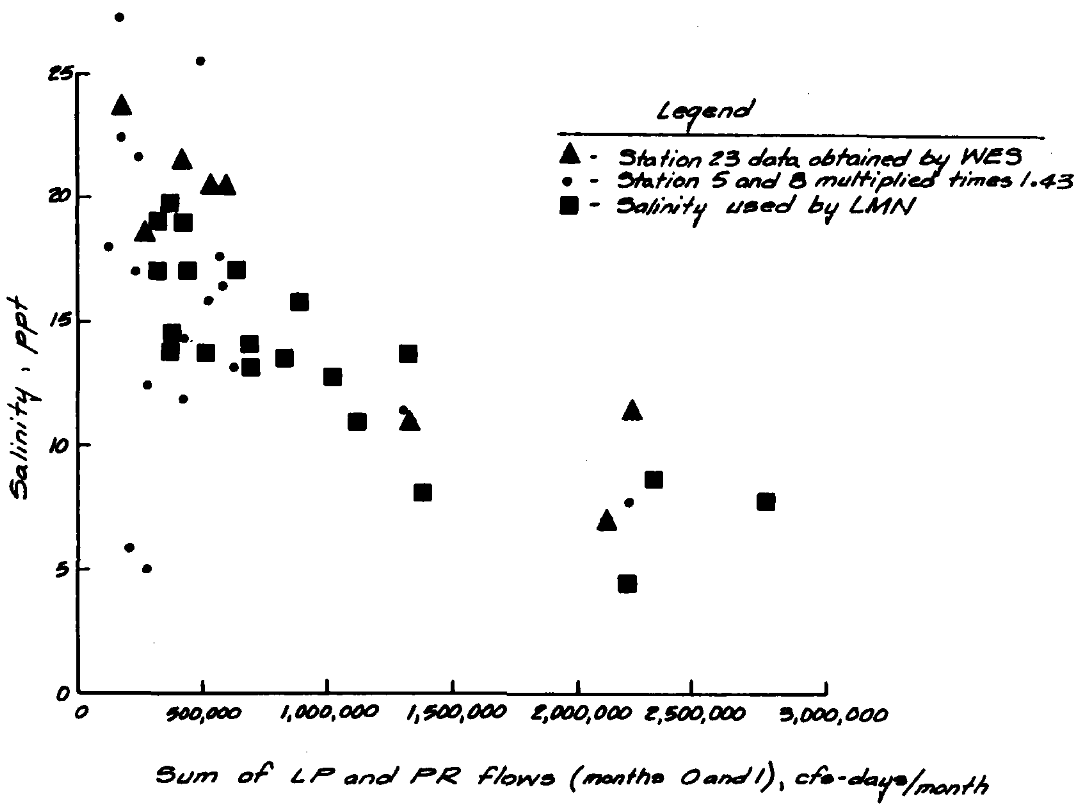


Figure 11. Comparison of the New Orleans District and WES salinity data for combined flows

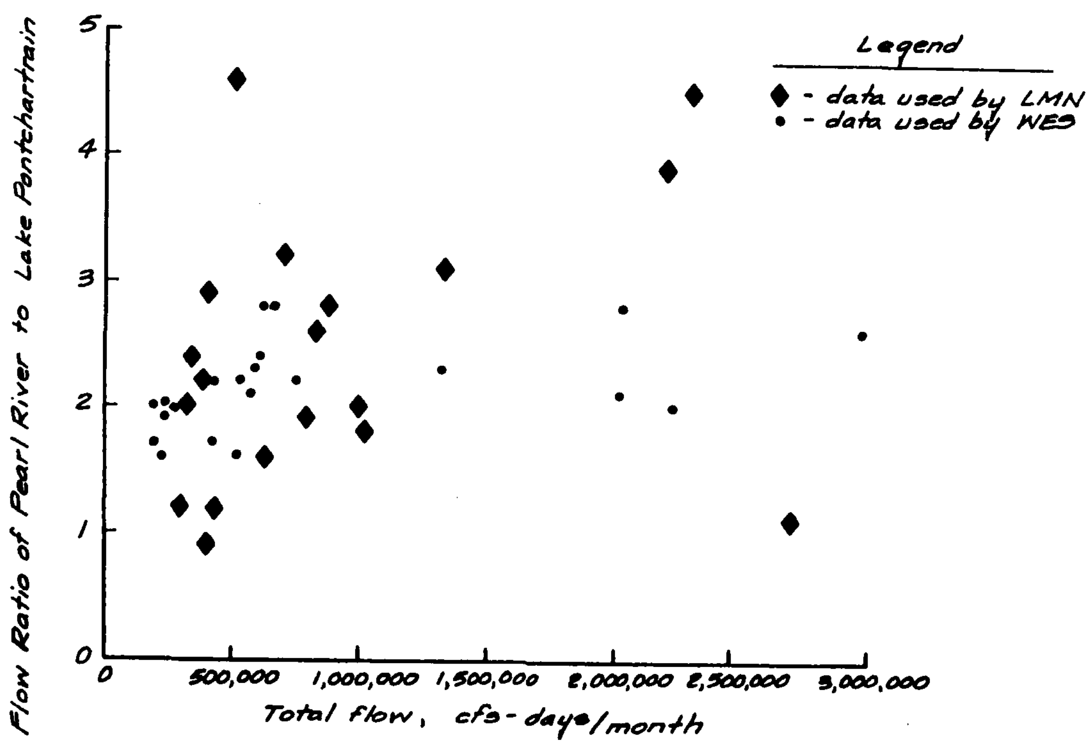


Figure 12. Comparison of the Pearl River and Lake Pontchartrain flow ratios

PART III: ANALYSIS

The SAS Computer Programs

22. The SAS (Statistical Analysis System) is a series of interrelated computer software packages for data analysis, management, and presentation. To the basic package, additional and more powerful software can be added. This analysis used SAS version 6.03 base software. Two other SAS packages were also used: SAS/STAT, operated on a Zenith PC model ZWX-248 using a Z-DOS operating system, and SAS/ETS, which was operated on an IBM 4331 computer. The SAS/STAT package contains more powerful and advanced statistical procedures than those found in the SAS base software. The SAS/ETS package is also an advanced statistical package and contains the procedures for time series analysis.

23. The regression procedures in the data analysis were accomplished using the General Linear Model (GLM) procedure and the Nonlinear Model (NLIN) procedure, which yielded similar results. Within the NLIN model, partial derivatives must be made and the regression equation written for the arguments, whereas within the GLM model, the various parameters are entered into an equation and then into a model statement. Due to the ease of use, the GLM was the preferred procedure.

Calculation of Salinity Flux

24. Salinity flux was calculated by executing a series of computational programs on the data from the ENDECO current meters. A description of the procedures and other data is presented in Part IV.

General Data Analysis

Daily averaging

25. Because the usage of super and mainframe computers can be costly, it was decided to reduce the amount of data to a manageable quantity. By using the daily averaged salinity data rather than hourly values, the amount of data was significantly reduced, and subsequently, computer time and costs. The daily averaging was accomplished using SAS subroutine PROC MEANS.

Month averaging

26. Streamflow, air temperature, and precipitation data were obtained as daily mean values. To use these data, it was decided to include monthly averaging as another way to display and study variation. The data were entered into another file according to variables. Using an SAS time function, calendar dates were assigned to the data. Finally, the means procedure was used to average the data by month (Figures 13-21). The salinity data were obtained from the New Orleans District, Louisiana Department of Fish and Wildlife, and the WES field collection program. The salinity data obtained by the WES field data collection program were in 30-min increments from an Aanderraa salinity meter and point data from the field surveys. The data were averaged to obtain daily means and those in turn were averaged to obtain monthly means. The data from the Louisiana Department of Fish and Wildlife and the New Orleans District were obtained as monthly mean salinities.

cfs-days and streamflow lumping

27. The USGS streamflow data were used as input to the SAS model in units of cfs-days. Simply stated, 1 cfs-day is 1 cfs flowing past a gaging station for a 24-hr period. The total monthly flow is the sum of the cfs-days for that 1-month period. These data, along with the precipitation, account for the freshwater inflow. Precipitation was represented as a flow by multiplying the total rainfall amount for the month times the study area. The result was then divided by the number of days in the month, which, when converted for units, yielded a flow rate with units of cubic feet per second. The streamflow input was broken into two parts: the Pearl River alone, and the Amite, Tangipahoa, Tickfaw, Tchefuncta, and Natalbany rivers lumped, and grouped, together to represent inflow to Lake Pontchartrain.

Missing or incorrect data

28. Missing data or data of questionable accuracy were represented in time series analysis as special values. A "missing statement" was included in the data to define these special values. In this way the SAS recognized that the data are indeed missing and that zeroes will not be substituted, thereby giving false results. In the regression models and a few of the basic statistical procedures, the SAS is able to deal with missing data. However, within time series analysis procedures, missing values are not allowed by SAS.

Lagged variables

29. The quantities of freshwater inflow were lagged to represent

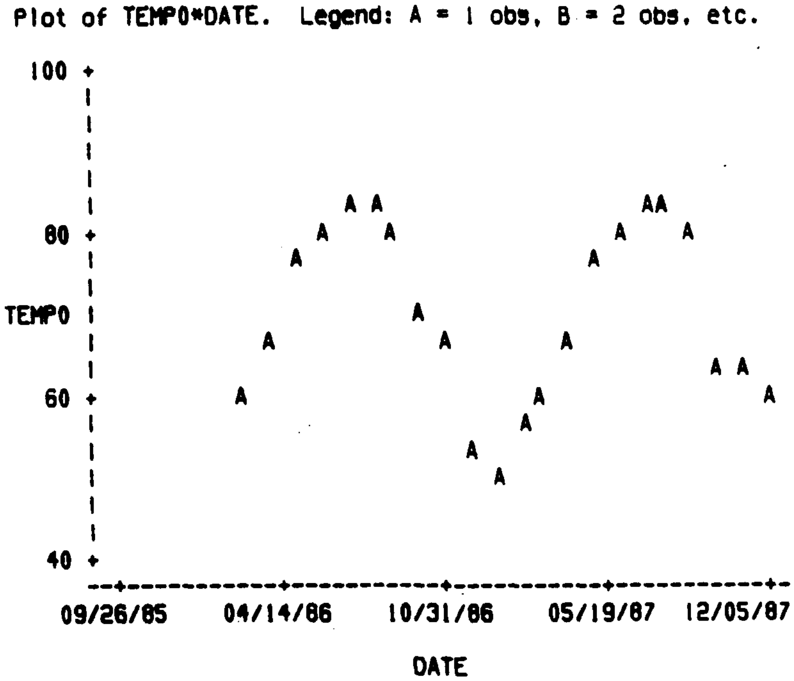


Figure 13. Average temperature by month in Bay Boudreau

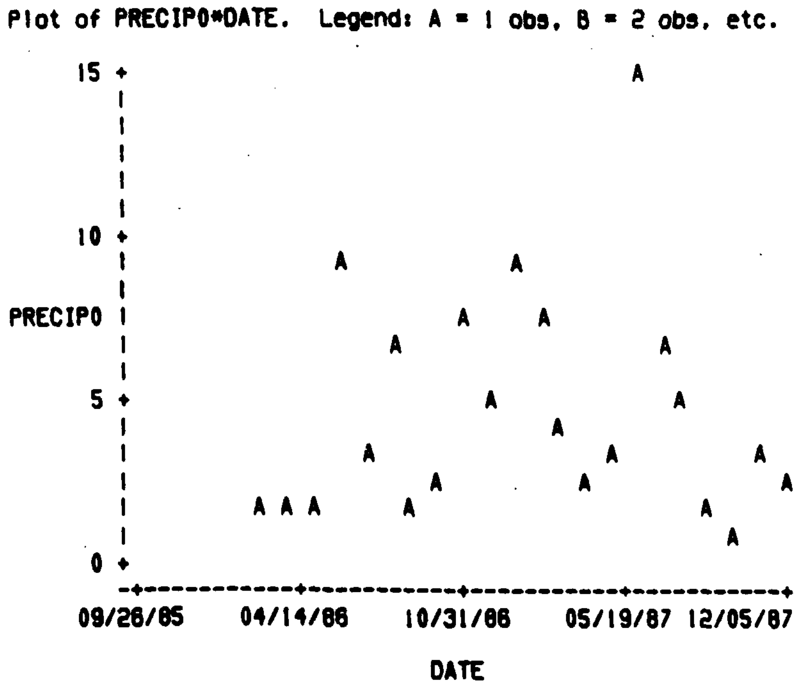


Figure 14. Total precipitation by month in Bay Boudreau

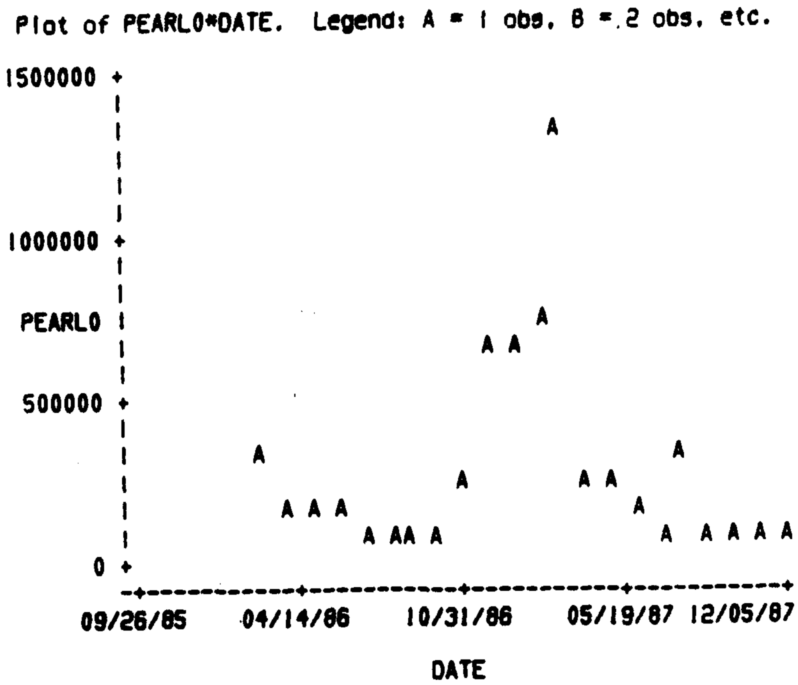


Figure 15. Streamflows in the Pearl River at Bay Boudreau

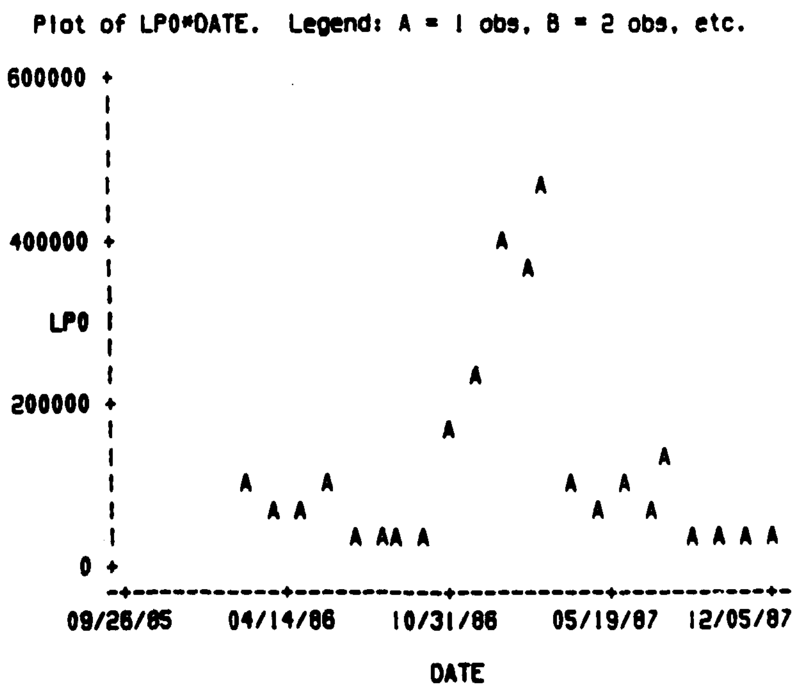


Figure 16. Streamflows in the Diversions at Bay Boudreau

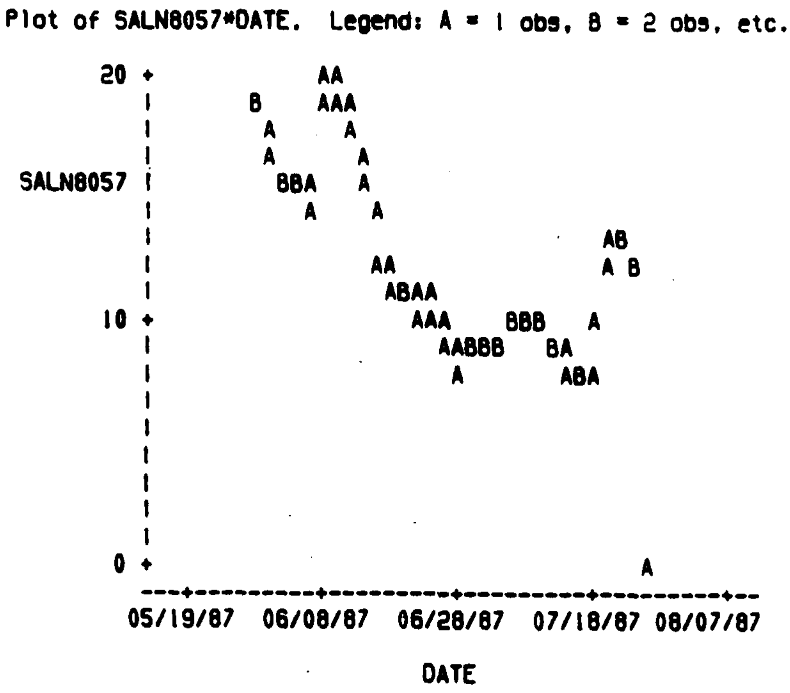


Figure 17. Daily salinity variation at station 8 in Bay Boudreau: May-July 1987

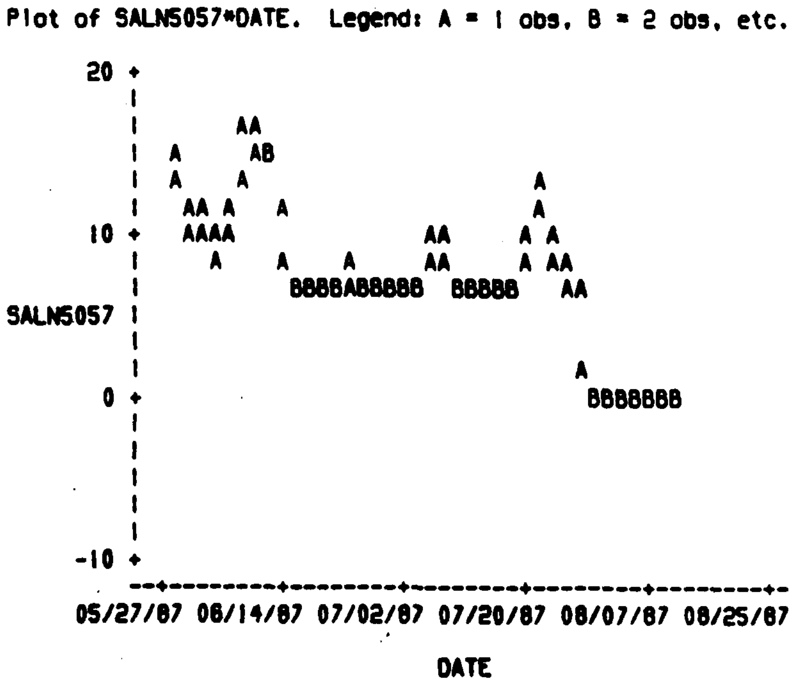
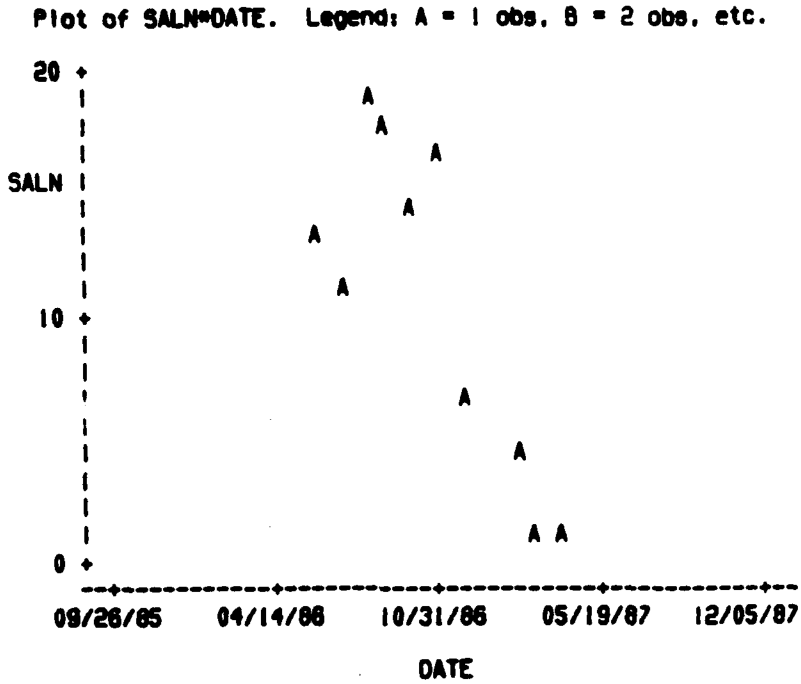


Figure 18. Daily salinity variation at station 8 in Bay Boudreau: May-August 1987



NOTE: 12 obs had missing values.

Figure 19. Monthly salinities at station 4 in Bay Boudreau

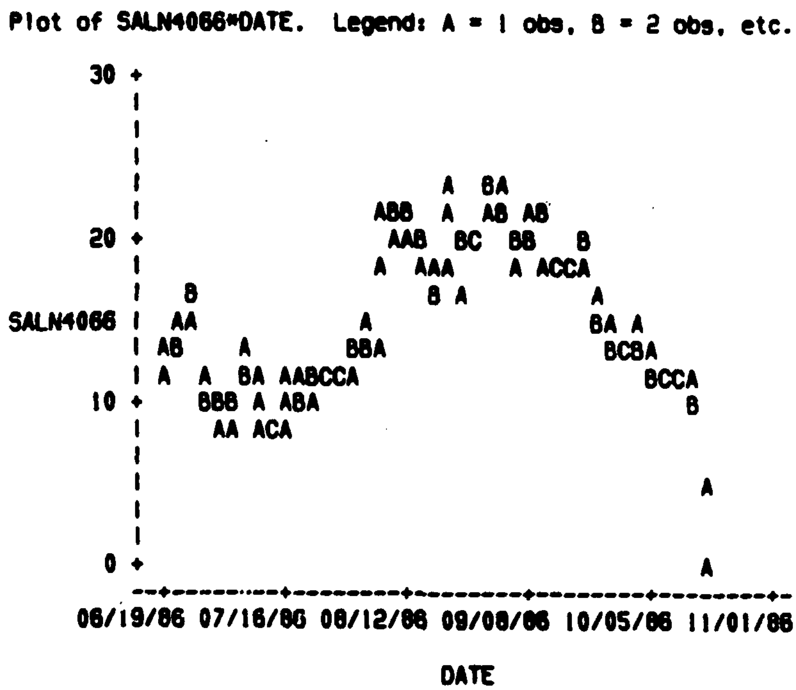


Figure 20. Daily salinity variation at station 4 in Bay Boudreau: June–October 1986

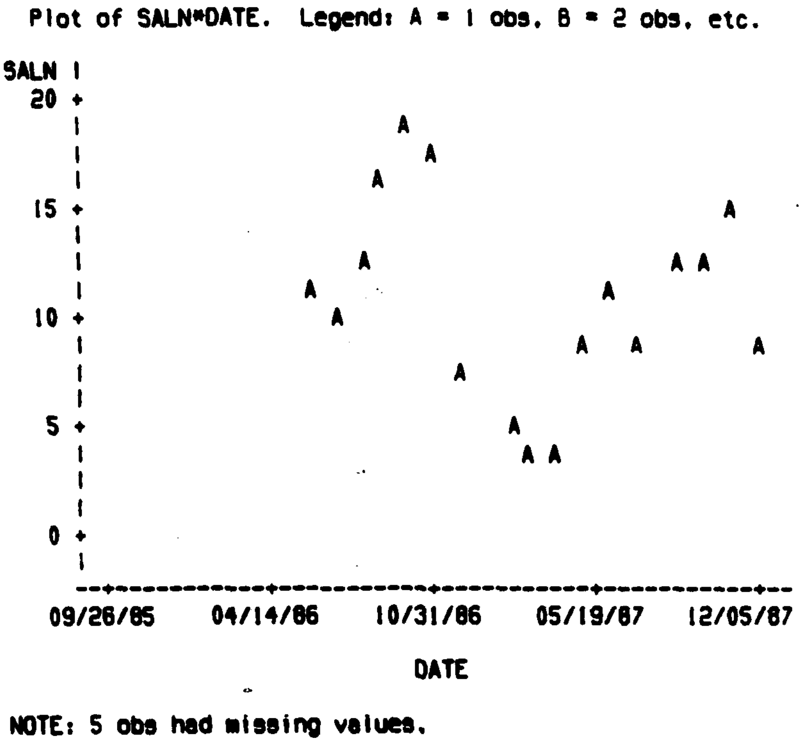


Figure 21. Monthly salinities at stations 5 and 8 in Bay Boudreau

delayed effects. *In the prototype*, fresh water arrives at certain points at different times; therefore, the use of lagging, which replicates the delay between input and response, emulates nature. The inflows were lagged manually 1 or 2 months (lag times were selected from cross-correlation results) and then entered into the regression model.

Regression analysis

30. Regression analysis is a method of describing the mathematical relationship among variables based on some specified model. Simple relationships can be deterministic when, with repeated experimentation, exactly the same results are given. In most cases, however, variable relationships are much more complicated. The relationships can only be described statistically. Statistical models were sought to describe variable relationships. Many models were tested by regression and compared.

PART IV: RESULTS

Salinity Flux

31. The calculation of the tidal-averaged currents and salinity flux components was accomplished by executing a series of computational programs on the data from the ENDECO current meters. The first program performed the necessary calculations for speed, direction, temperature, conductivity, and salinity. A second program was applied to reformat the data so that it could be viewed (Figure 22). A typical tidal cycle was then chosen and the U- and V-components of velocity and salinity flux components SU and SV (the product of salinity and velocity, with units of ppt-cm/sec averaged over one tidal cycle) were calculated.

32. Table 2 indicates the directions of movement for both the average tidal current and salinity flux for the survey periods. The directions are noted as N-S (north positive) and E-W (east positive). The data are also displayed graphically in Figures 23-30, and the directions of movement are indicated for both the average tidal current speed and salinity flux. The data were converted into the following components:

- a. V = N-S component (north positive), current speed
- b. U = E-W component (east positive), current speed
- c. SV = N-S component, mean salinity flux
- d. SU = E-W component, mean salinity flux

33. There is a wide variation in the flux values, most notably at station 12. Part of the explanation for these differences is that these areas experience changes in the drainage pattern from areas such as the Pearl River when high flows occur. This, in addition to the other naturally occurring phenomena such as tide and wind forces along the surface, produces complex circulation patterns within this estuary.

Drogue Movement

34. During the August 1986 intensive survey, four different sets of four drogues each were launched in the Lake Borgne region south of the Pearl River. The drogues were tracked between visits to sampling stations and the locations determined by Loran-C positioning. Several of these tests displayed

ENDECO Type 174SSM Solid State Current Meter
BAY BOUDREAU 0081 STA.29
Date: TUE 21-OCT-1986 Julian date: 294

TIME	SPEED (KNOTS)	DIR (TRU)	TEMP (C)	COND (MS/CM)	DEPT (FT)	SALN (PPT)
18:02:00	.33	267	20.12	41.52	.01	29.74
18:12:00	.33	266	20.16	41.55	.01	29.74
18:22:00	.30	267	20.25	41.70	.01	29.81
18:32:00	.31	265	20.31	41.86	.01	29.86
18:42:00	.35	267	20.37	42.02	.01	29.96
18:52:00	.35	268	20.41	42.14	.01	30.03
19:02:00	.37	267	20.47	42.24	.01	30.04
19:12:00	.34	266	20.49	42.36	.01	30.13
19:22:00	.38	269	20.51	42.48	.18	30.21
19:32:00	.40	267	20.49	42.58	.45	30.30
19:42:00	.40	266	20.45	42.61	.54	30.35
19:52:00	.41	266	20.41	42.61	.71	30.40
20:02:00	.42	266	20.35	42.48	.89	30.36
20:12:00	.43	267	20.31	42.42	.89	30.34
20:22:00	.45	269	20.31	42.39	1.07	30.27
20:32:00	.48	271	20.31	42.33	1.34	30.28
20:42:00	.49	270	20.25	42.42	1.34	30.38
20:52:00	.48	270	20.22	42.30	1.60	30.29
21:02:00	.49	272	20.22	42.42	1.42	30.36
21:12:00	.47	272	20.22	42.48	1.60	30.38
21:22:00	.47	271	20.31	42.67	1.68	30.50
21:32:00	.47	270	20.31	42.61	1.78	30.47
21:42:00	.48	270	20.31	42.73	1.78	30.59
21:52:00	.48	271	20.29	42.67	1.78	30.57
22:02:00	.50	270	20.29	42.61	1.78	30.48
22:12:00	.50	269	20.27	42.61	1.78	30.50
22:22:00	.50	270	20.29	42.61	1.78	30.48
22:32:00	.51	269	20.23	42.61	2.04	30.51
22:42:00	.48	269	20.22	42.61	1.87	30.54
22:52:00	.49	269	20.22	42.61	1.78	30.54
23:02:00	.49	270	20.22	42.58	1.87	30.53
23:12:00	.51	269	20.22	42.55	1.87	30.53
23:22:00	.49	272	20.22	42.61	1.95	30.54
23:32:00	.49	271	20.22	42.61	1.95	30.54
23:42:00	.47	270	20.20	42.48	2.04	30.48
23:52:00	.45	269	20.14	42.48	1.87	30.51

Figure 22. An example printout of the reformatted ENDECO current meter data

Table 2

Current and Salinity Flux at Selected Stations

Station Number	Depth* ft	Current, cm/sec V	Current, cm/sec U	Salinity Flux, ppt-cm/sec SV	Salinity Flux, ppt-cm/sec SU
		August 1986 Survey			
11	S-3	4.1	4.1	6.9	6.9
11	B+3	-1.5	-1.5	-23.7	-14.9
28	B+3	0.0	-0.5	-1.5	-9.3
29	B+3	-4.1	1.0	-82.4	-4.6
32	S-3	2.1	2.1	43.2	17.0
32	B+3	-1.6	-0.4	-23.6	-15.3
		October 1986 Survey			
12	S-3	-1.0	-1.0	-21.1	-17.5
12	B+3	0.5	0.0	4.1	-5.7
29	M	-2.6	-2.6	-3.1	-2.1
32	S-3	-1.0	0.51	-28.8	10.3
32	B+3	-1.5	1.5	-36.5	34.0
		February 1987 Survey			
12	S-3	-2.1	23.2	-7.7	134.4**
12	B+3	-0.5	22.1	-1.0	256.9**
32	B+3	-3.6	15.4	0.0	0.0
		April 1987 Survey			
11	S-3	0.0	-2.1	-1.5	-9.8
11	B+3	0.5	-4.1	0.0	0.0
12	B+3	1.0	-2.6	2.6	-5.1
32	S-3	-1.0	-1.5	0.0	-0.5
32	B+3	-1.5	-2.6	-5.1	-6.7

* The depth is noted as 3 ft below the surface (S-3), middepth (M), and 3 ft above the bottom (B+3).

** The reason for the extremely large value is not clear, refer to text.

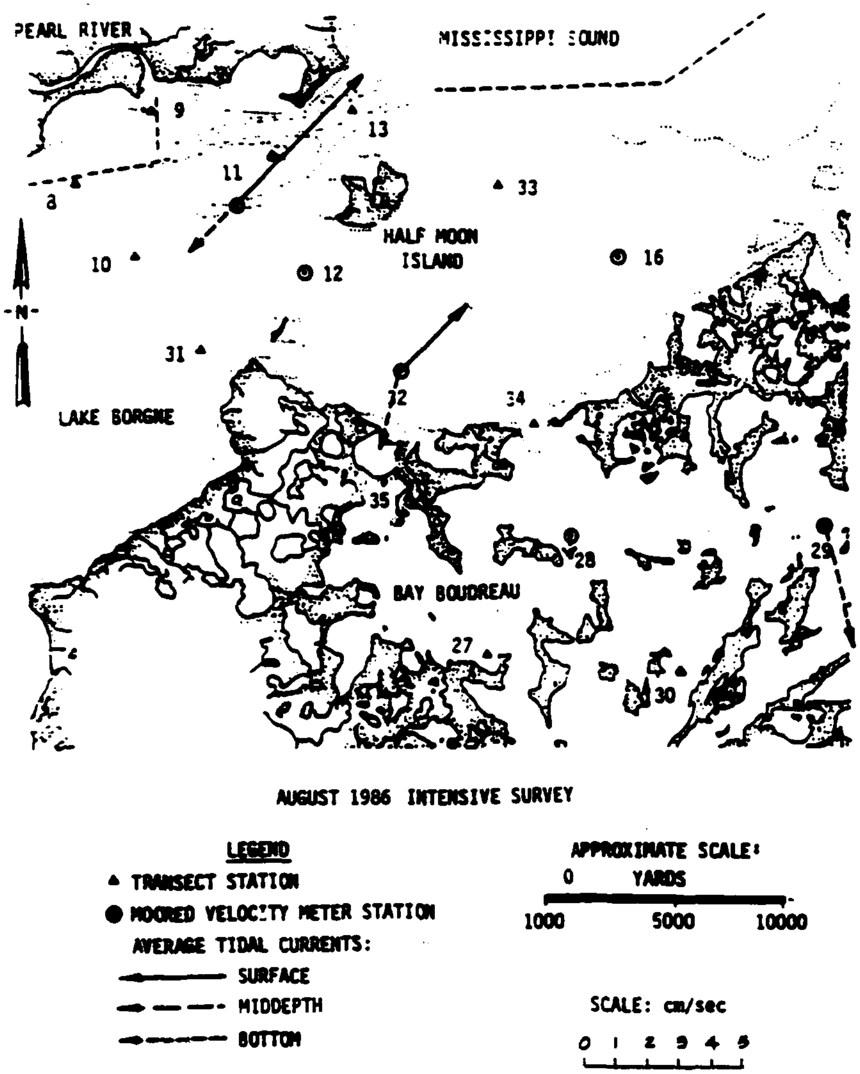


Figure 23. Average tidal current movement, August 1986

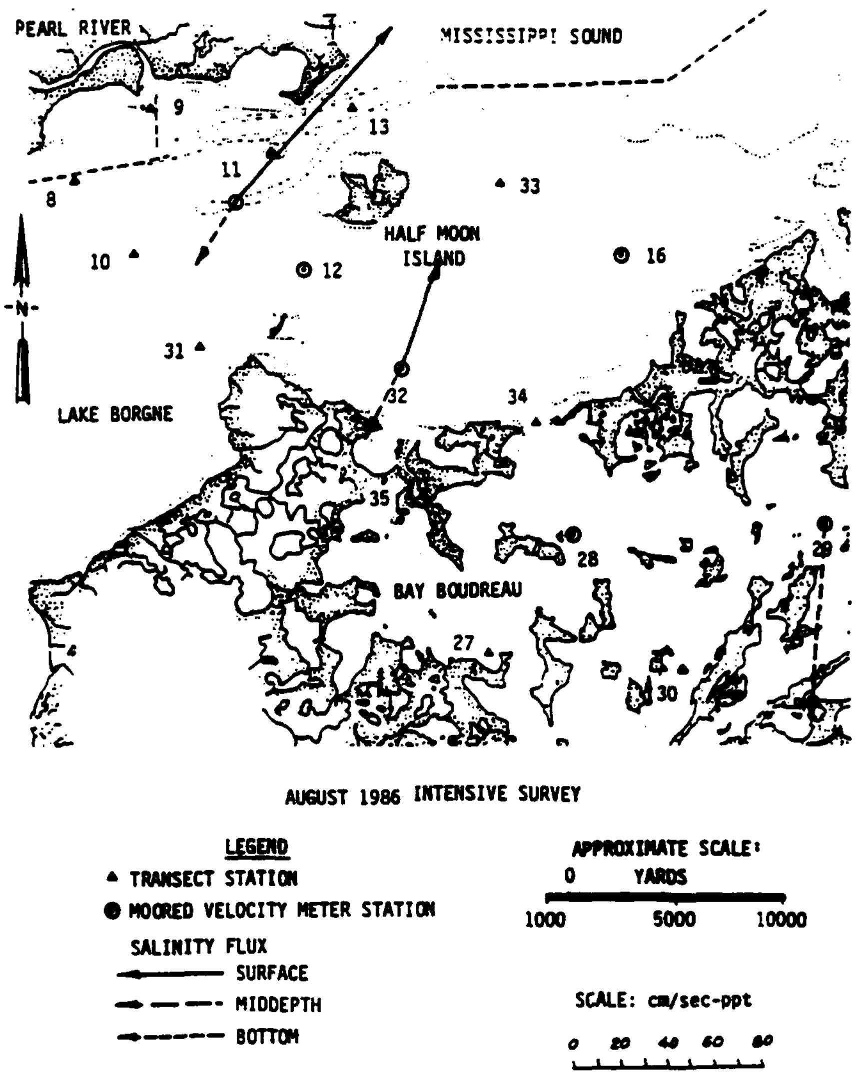


Figure 24. Average salinity flux, August 1986

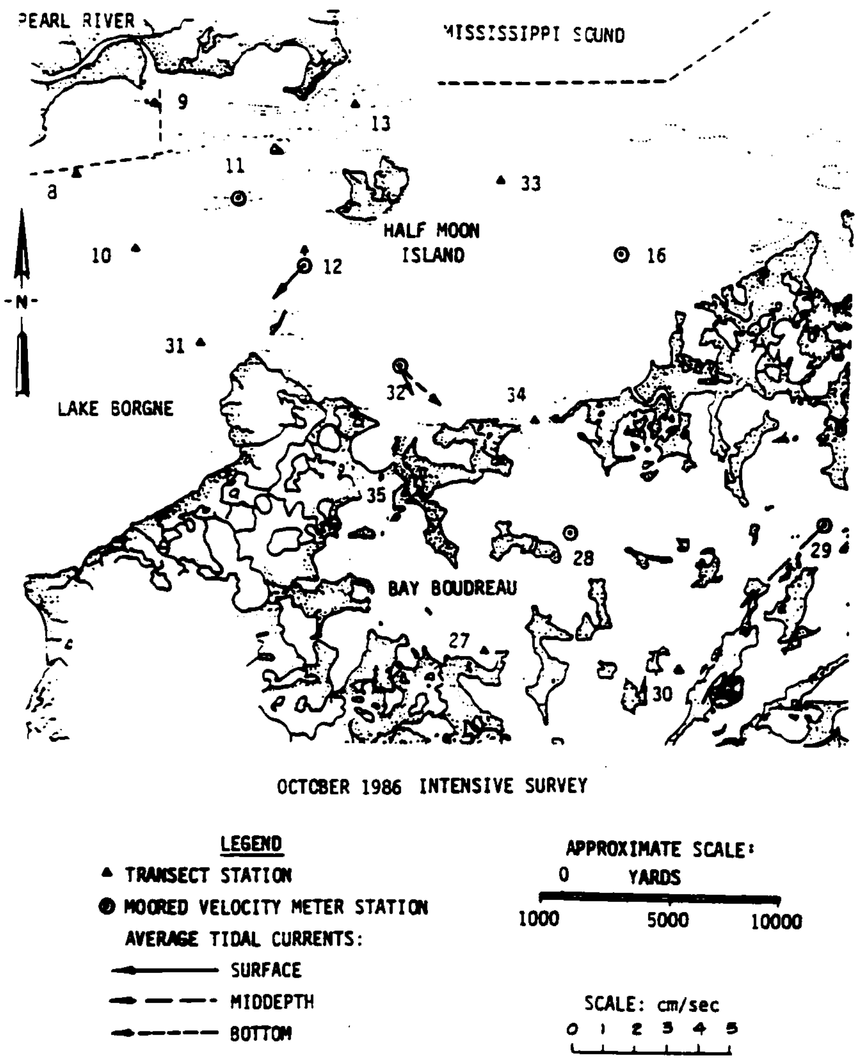


Figure 25. Average tidal current movement, October 1986

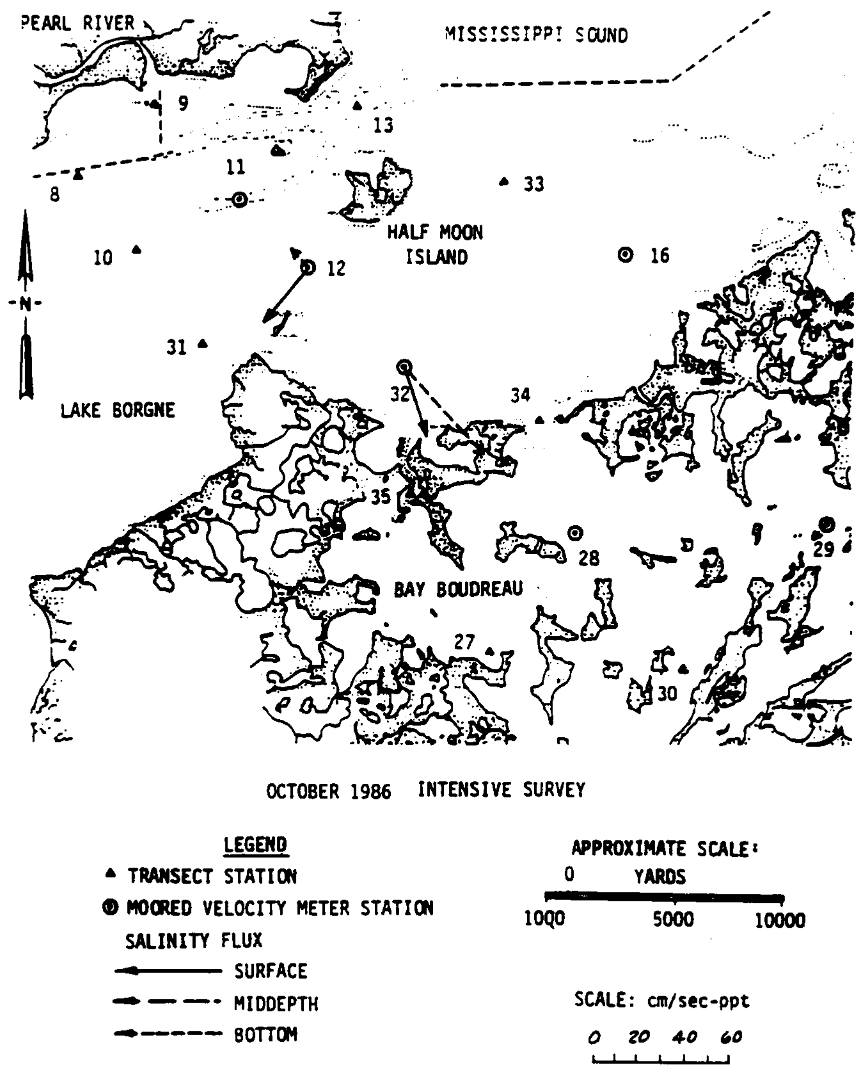


Figure 26. Average salinity flux, October 1986

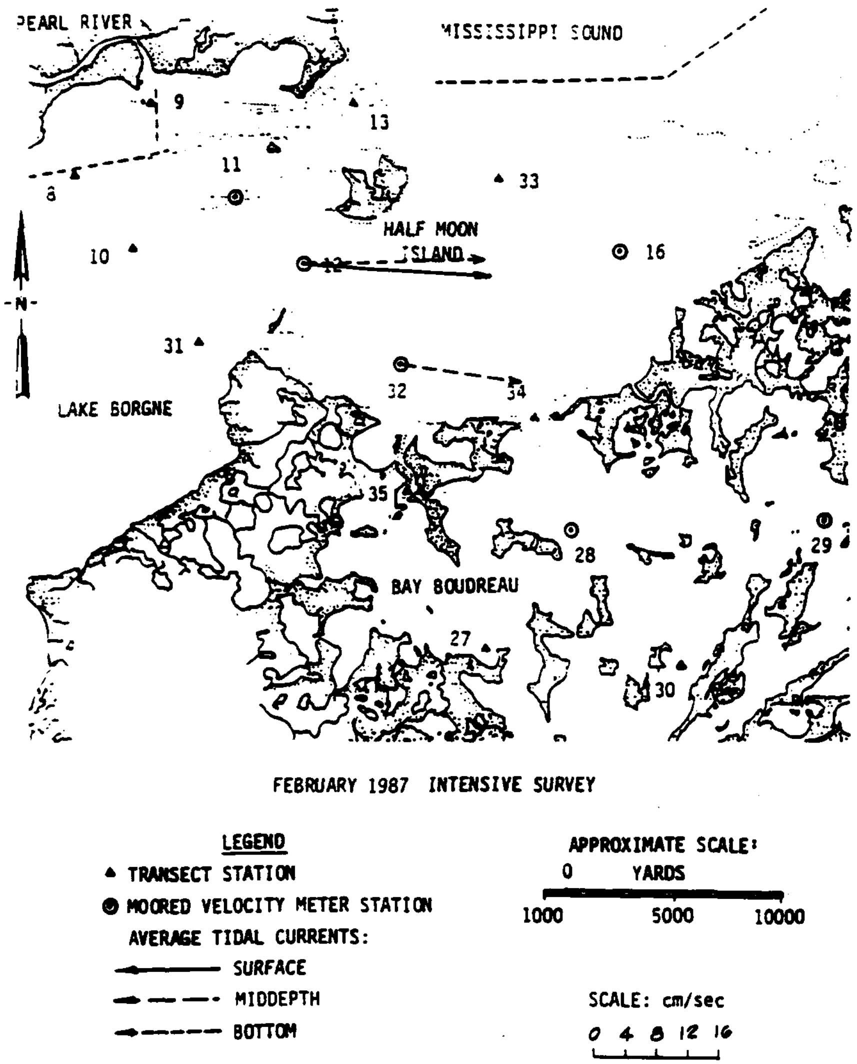


Figure 27. Average tidal current movement, February 1987

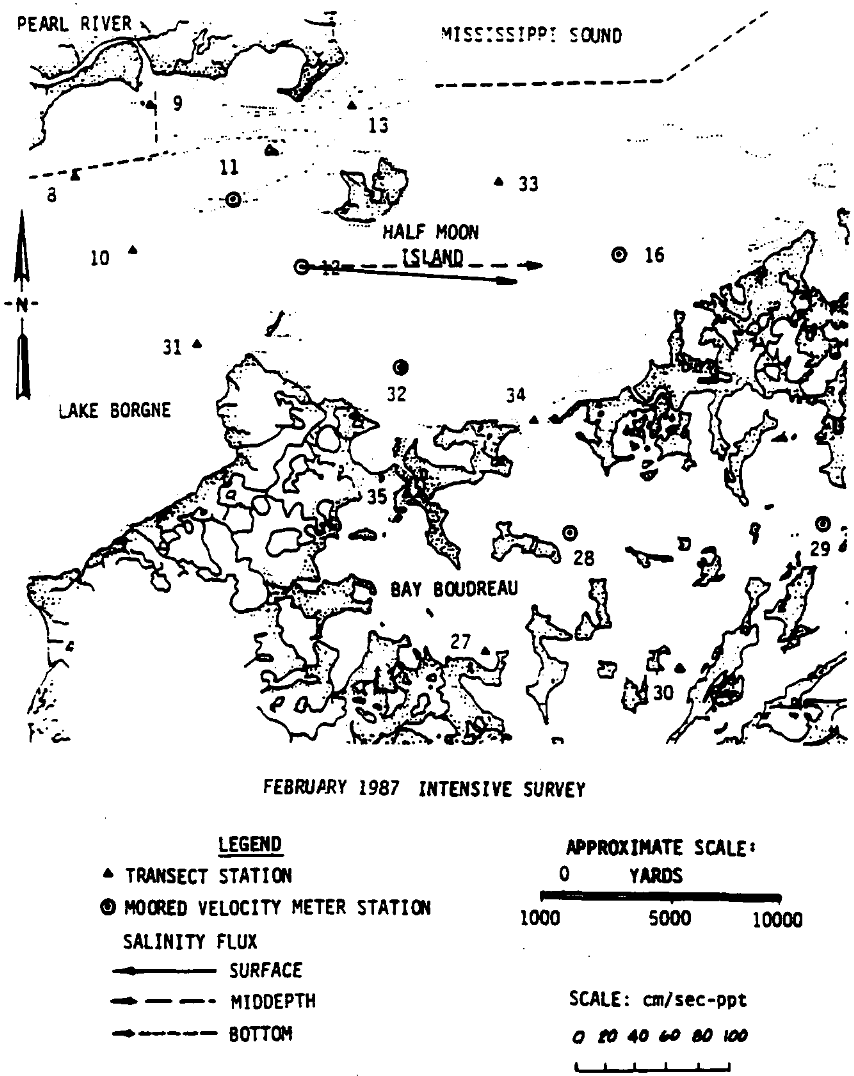


Figure 28. Average salinity flux, February 1987

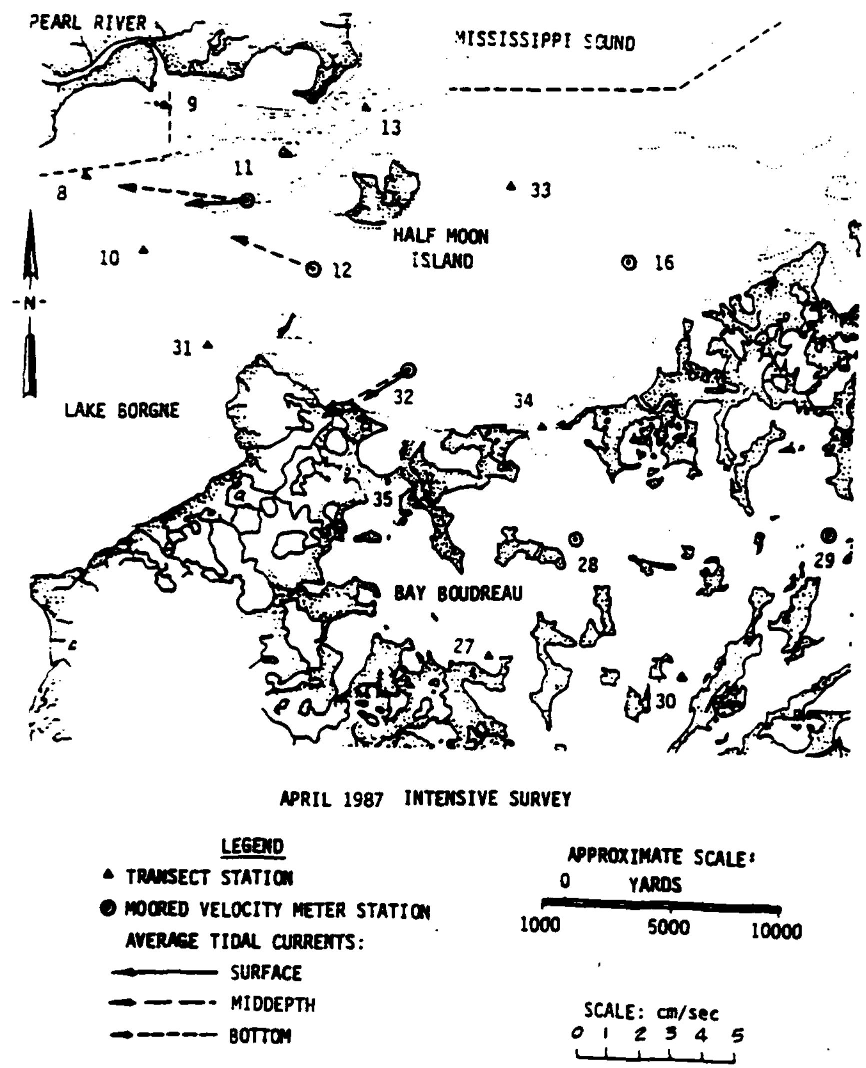


Figure 29. Average tidal current movement, April 1987

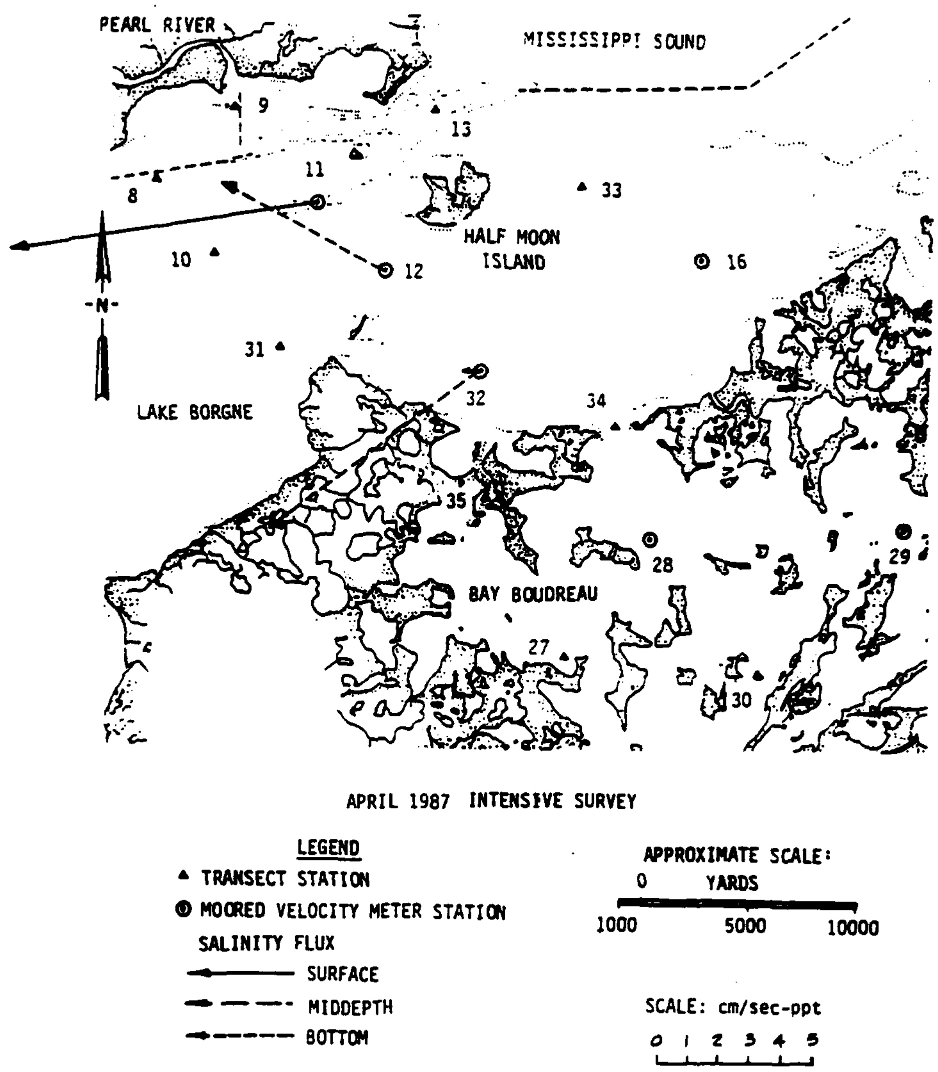


Figure 30. Average salinity flux, April 1987

little or no movement. However, three of the series did indicate some movement in the area just north of Bay Boudreau (Figures 31-33). The following observations were made about the movements:

- a. High water occurred at 0445 on 13 Aug 86. The first test group of drogues was deployed at 0709 and started moving in a northwesterly course. The drogues were retrieved at 0930 moving in the same direction.
- b. The second test group was also conducted on 13 Aug 86. This group was deployed at 1000 and moved in a northeasterly direction. The drogues were retrieved at 1200 while moving in the same direction.
- c. During the 14 Aug 86 test (Figure 33), the indications are that a northerly flood flow prevailed at D and C; however, a deflection occurred at A and B that suggests the possibility of a gyre induced by the flood tide, circulating to the west and then to the east, complementing an eastward ebb flow.

Summary of Transport Patterns

35. Streamflows in the Pearl River and the Lake Pontchartrain tributaries were much below normal in the spring of 1986. During the period of fall 1986 through spring of 1987, streamflows were above normal. Thus the hydrology of the system during the WES field data collection could be considered atypical.

36. Surface drogues indicated that in St. Joe Pass, flood tidal flows are from the southeast quadrant while ebb tidal flows are from the southwest quadrant. This might indicate a clockwise circulation north of Bay Boudreau during the sampling period (Figure 34). Flows within Bay Boudreau were toward the south.

37. Average tidal-averaged flows and salinity fluxes indicate that two-level estuarine-type circulation can develop during periods of low streamflow (such as during August 1986), but can be overwhelmed by other circulation features during low flow (October 1986) and especially during high flow (February 1987). Salinity fluxes were in the same direction as the average flow.

Comparison of WES and LMN Regression Models

38. The New Orleans District developed by regression the LMN model that

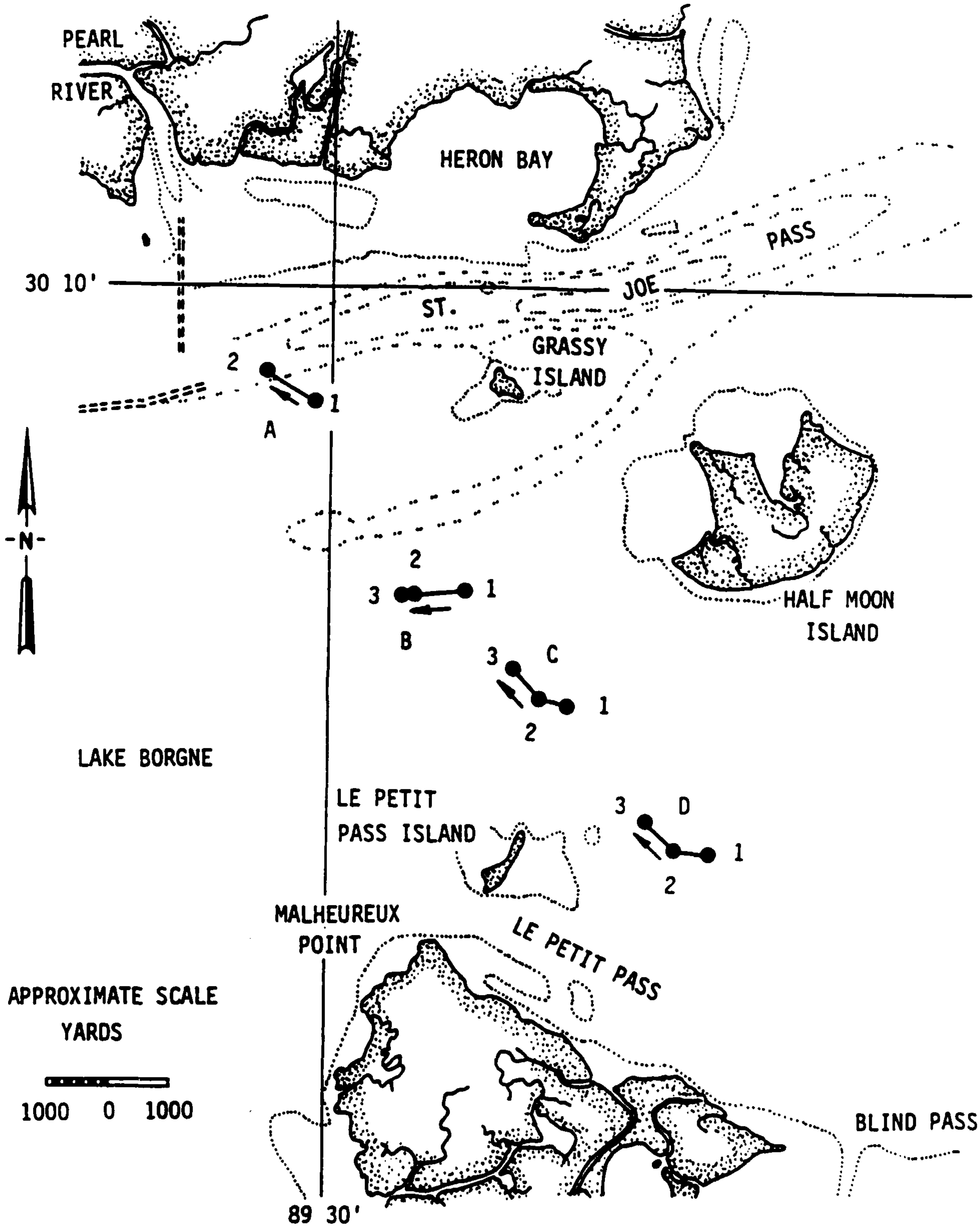


Figure 31. Movement of drogues in Lake Borgne on 13 Aug 86 (Test 1)

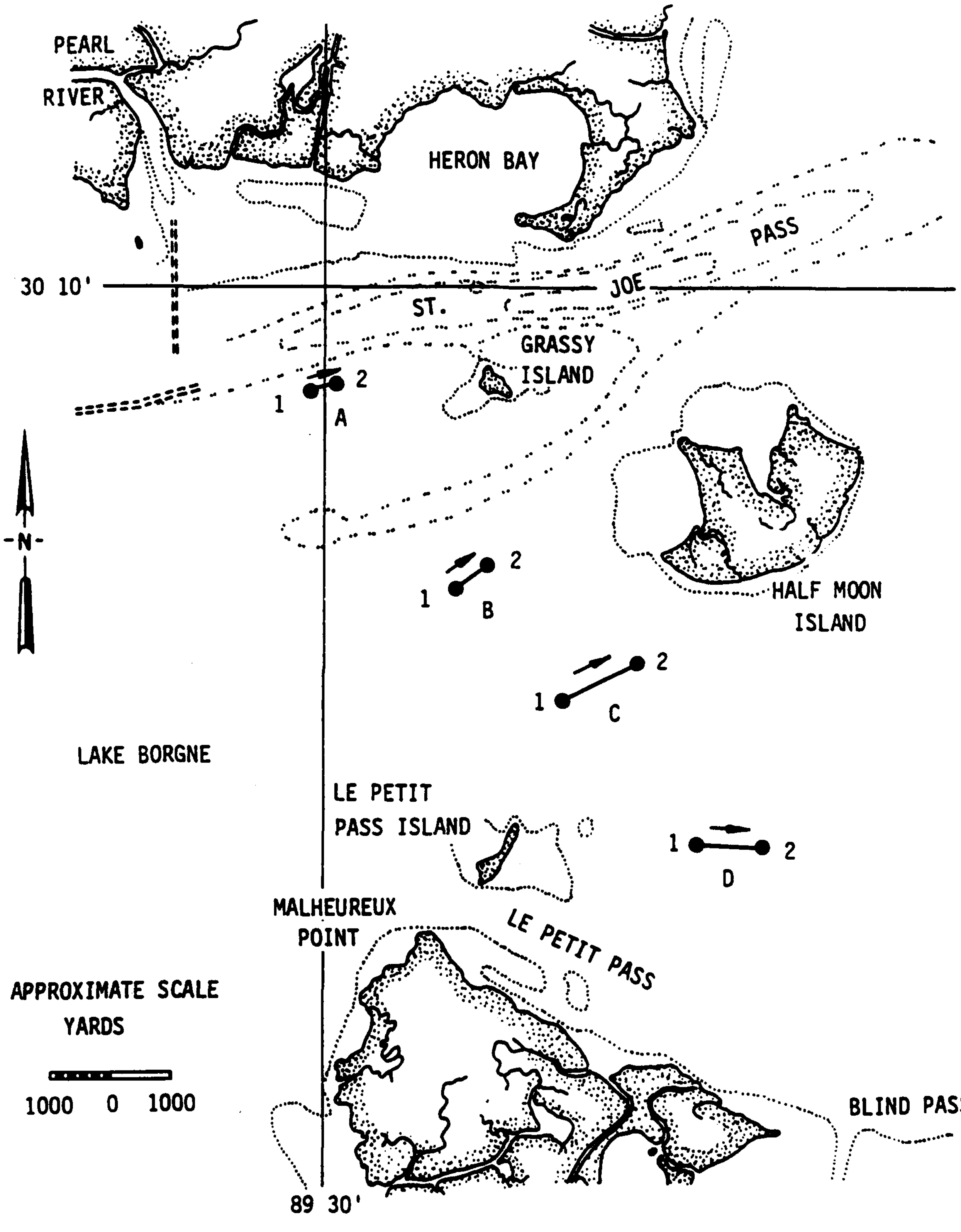


Figure 32. Movement of drogues in Lake Borgne on 13 Aug 86 (Test 2)

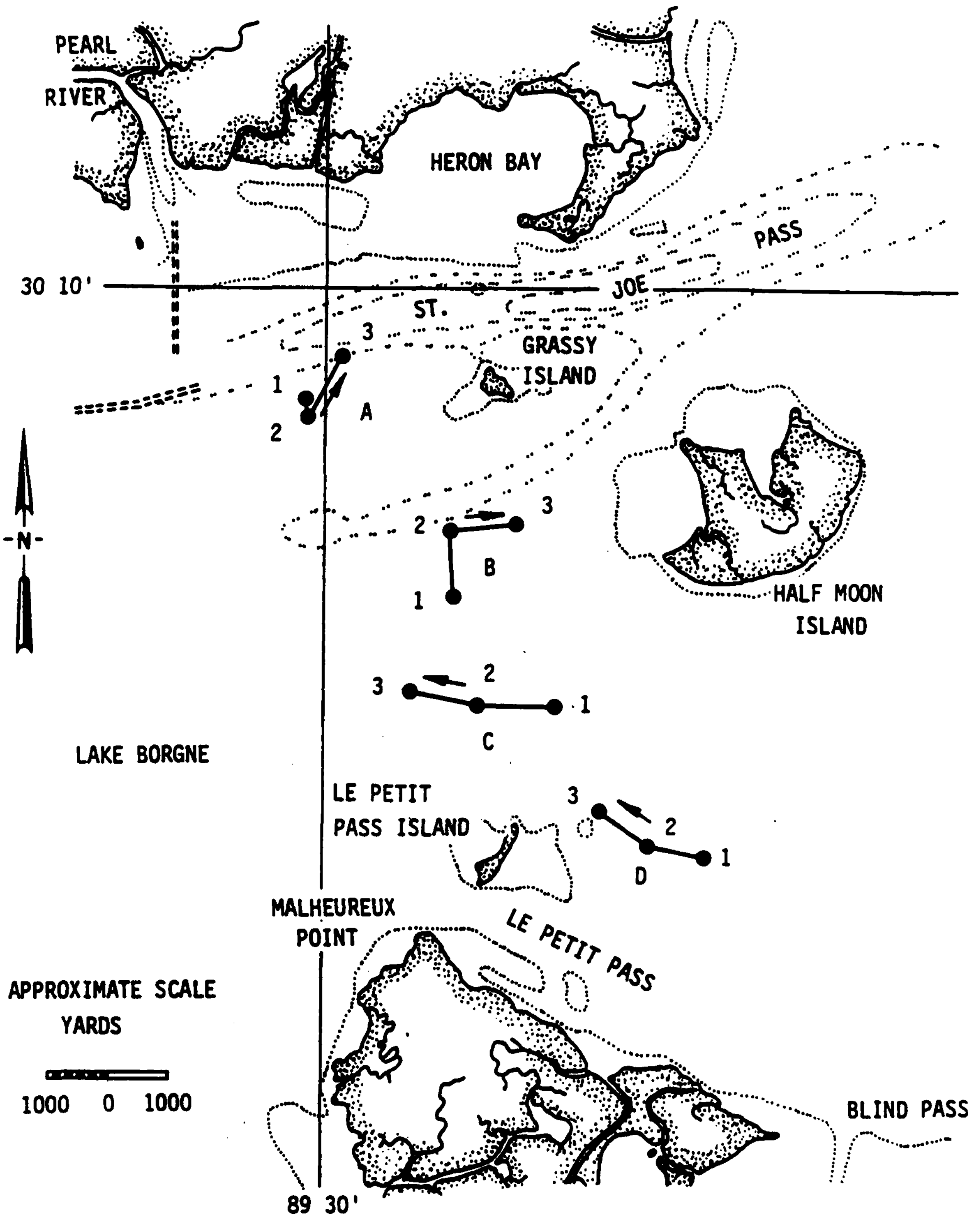


Figure 33. Movement of drogues in Lake Borgne on 14 Aug 86

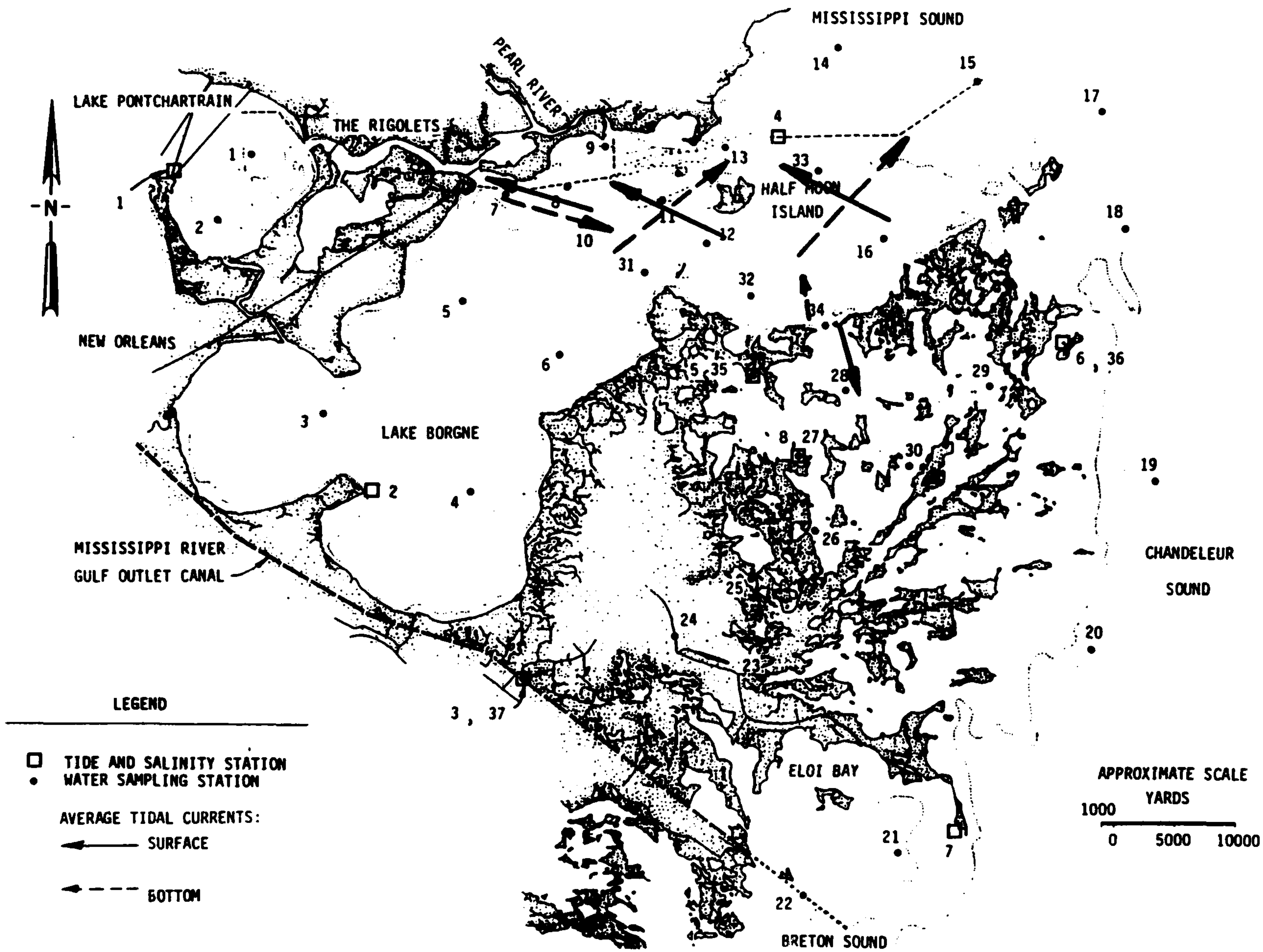


Figure 34. Hypothesized flow patterns (based on apparent movement of drogues and fluxes)

related monthly salinity to the present month's flow of the Pearl River, and the present and previous month's flow of Lake Pontchartrain and the Pearl River combined. The Lake Pontchartrain flow was represented as a combination of the Amite, Tickfaw, Tchefuncta, Natalbany, and Tangipahoa river flows. The salinity data were obtained at Treasure Pass in Bay Boudreau. Twenty-one observations used in the LMN model were for the period 1971-1978.

39. WES also used regression to develop a model relating salinity to the present Pearl River and Lake Pontchartrain flows (Table 3). In the WES models the flows were lagged twice by using flows from the previous 2 months. Precipitation for the corresponding months was also included in the WES models. Evaporation was also examined, but was found not to have a significant effect in model results. WES used this method of lagging flows one and two times as a means of predicting salinity when the current flows were unknown. Data from the period 1986-1987 as described in Part II were used in the development of the WES models. Model 10a, however, combined the WES data plus the 1971-1978 data.

40. In comparing the LMN and WES models, r^2 values were used (Table 3). How well a regression conforms to a data set is represented by an r^2 value ranging from 0 to 1. A value of 1 represents a perfect conformation to the data set, whereas a value of 0 suggests that there is no relationship between the data set and the equation.

41. The prototype data compiled by this study were entered as previously described into the SAS/GLM procedure to determine the regression coefficients and the r^2 values for the WES and LMN models. The following independent variables were used in the development of the regression models:

- a. LP0: Current Lake Pontchartrain tributary inflows
- b. LP1: Lake Pontchartrain inflows lagged 1 month
- c. LP2: Lake Pontchartrain inflows lagged 2 months
- d. PEARL0: Current Pearl River discharge
- e. PEARL1: Pearl River discharge lagged 1 month
- f. PEARL2: Pearl River discharge lagged 2 months
- g. RF0: Total precipitation for the current month expressed as a flow
- h. RF1: Total precipitation lagged 1 month expressed as a flow
- i. RF2: Total precipitation lagged 2 months expressed as a flow

Tables 3 and 4 present the results of the first nine regressions, designated

Table 3

Comparison of LMN Regression Model with WES Regression Models, Unadjusted

	Model	Station 4 r^2	Stations 5 and 8, r^2
M1.	&SALN = B1 * ln (A) + B2 * ln (C) + I where SALN = salinity B1 = model coefficient ln = natural logarithm A = PEARL0+PEARL1+LP1 B2 = model coefficient C = LP0 I = intercept	0.87	0.70
M2.	SALN = B1 * ln (A) + B2 * ln (C) + I where A = LP1 + RF1 C = PEARL2	0.76	0.75
M3.	SALN = B1 * ln (A) + B2 * ln (C) + I where A = LP1 + RF2 C = PEARL2	0.68	0.56
M4.	SALN = B1 * ln (A) + B2 * ln (C) + I where A = LP1 C = PEARL2 + RF2	0.91	0.75
M5.	SALN = B1 * ln (A) + B2 * ln (C) + I where A = LP1 C = PEARL2 + RF1	0.93	0.78
M6.	SALN = B1 * ln (A) + B2 * ln (C) + I where A = LP1 C = LP2	0.91	0.76
M7.	SALN = B1 * ln (A) + I where A = LP2	0.59	0.46
M8.	SALN = B1 * ln (A) + B2 * ln (C) + I where A = LP1 C = PEARL2	0.92	0.77
M9.	SALN = B1 * ln (A) + I where A = LP1	0.90	0.75

Note: & denotes LMN model.

Table 4

Model Coefficients of the LMN and WES Regression Models

Model		Station 4 Coefficients	Stations 5 and 8 Coefficients
M1.	&SALN = B1 * ln (A) + B2 * ln (C) + I	B1=-7.7984	B1=-5.7657
	where SALN = salinity	B2= 2.4207	B2= 2.1960
	B1 = model coefficient		
	ln = natural logarithm	I=86.72	I=60.88
	A = PEARL0 + PEARL1 + LP1		
	B2 = model coefficient		
	C = LP0		
	I = intercept		
M2.	SALN = B1 * ln (A) + B2 * ln (C) + I	B1=-5.9078	B1=-3.5130
	where A = LP1 + RF1	B2= 0.5451	B2=-1.6227
	C = PEARL2	I=74.29	I=72.64
M3.	SALN = B1 * ln (A) + B2 * ln (C) + I	B1=-5.7133	B1=-2.4122
	where A = LP1 + RF2	B2= 0.3130	B2=-1.9117
	C = PEARL2	I=77.19	I=62.88
M4.	SALN = B1 * ln (A) + B2 * ln (C) + I	B1=-6.4148	B1=-4.2077
	where A = LP1	B2= 1.9887	B2=-0.3589
	C = PEARL2 + RF2	I=61.52	I=63.15
M5.	SALN = B1 * ln (A) + B2 * ln (C) + I	B1=-8.6156	B1=-3.4615
	where A = LP1	B2= 3.5190	B2=-1.3683
	C = PEARL2 + RF1	I=66.08	I=67.35
M6.	SALN = B1 * ln (A) + B2 * ln (C) + I	B1=-6.6878	B1=-3.8800
	where A = LP1	B2= 0.8234	B2=-0.7937
	C = LP2	I=79.43	I=63.97
M7.	SALN = B1 * ln (A) + I	B1=-5.3240	B1=-3.4211
	where A = LP2	I=44.57	I=49.73
M8.	SALN = B1 * ln (A) + B2 * ln (C) + I	B1=-7.5807	B1=-3.7513
	where A = LP1	B2= 1.8062	B2=-0.8975
	C = PEARL2	I=76.42	I=64.38
M9.	SALN = B1 * ln (A) + I	B1=-6.0454	B1=-4.4448
	where A = LP1	I=54.79	I=61.36

Note: & denotes LMN model.

as models M1 to M9. M1 is the form used in the original LMN regression. Each equation was fit to 1986-87 data from station 4 and the average of stations 5 and 8 (see Figure 3). Note that model M1 uses the form of the LMN model but generates coefficients based on the WES-collected data.

42. The overall best fits were models M5 and M8. However, numbers M5 and M8 had positive B2 model coefficients for station 4. This would imply that as the Pearl River flow increased, the corresponding salinity at station 4 would increase, an unrealistic result. Corresponding model coefficients for stations 5 and 8 were negative.

43. The LMN model and model coefficients were used to predict Treasure Pass salinities using the flows that occurred over the 22 months of this study. Nine samples were collected at station 23, near Treasure Pass, and one at nearby station 24. Seven of the sample salinities were greater, often by 4 or 5 ppt, than the predicted salinities, while three were only slightly less. Salinities were, on average, 3.0 ppt greater than the predicted values, thus suggesting a forcing mechanism that is not included in the regression.

44. Models M2-M9 were considered unsatisfactory for this effort in that they did not represent an improvement over the LMN model. They also showed that the nonstationary nature of the data and the relative imbalance of Pearl River and Lake Pontchartrain flows tended to obscure salinity dependence on the Lake Pontchartrain flows. They are not used further here.

Normalizing and Weighting of Bay Boudreau Variables

45. The results of the regressions disclosed that the lag periods needed better definition. It was also evident that the Pearl River tended to conceal or overwhelm the contribution Lake Pontchartrain flows made. By developing a procedure that would weight and normalize the flows, the objective of defining required Lake Pontchartrain flows was more readily achieved.

46. Logarithmic regressions were run on the individual variables (e.g., PO, LPO, P4, etc.) to determine the correlation coefficients of the variables. The variables were the same ones used in the previous regression analyses conducted on the Bay Boudreau data.

47. Correlation coefficients versus lags for Lake Pontchartrain and the Pearl River were calculated and plotted (Figures 35-37). By using this graph, the relative influence of the Pearl River and Lake Pontchartrain flows

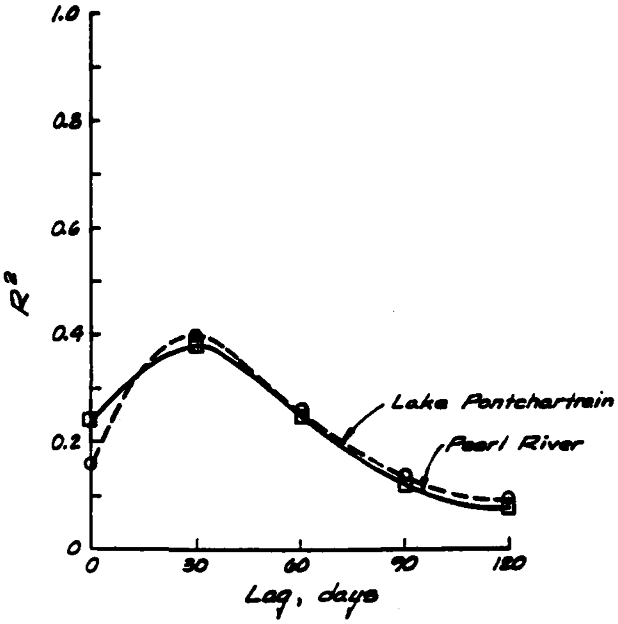


Figure 35. Cross-correlation between salinity and Pearl River and Lake Pontchartrain inflows (stations 5 and 8) for weighting purposes

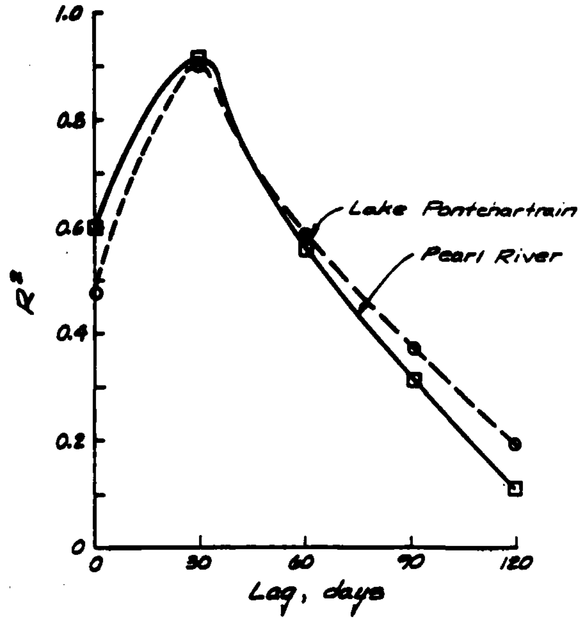


Figure 36. Cross-correlation between salinity and Pearl River and Lake Pontchartrain inflows (station 4) for weighting purposes

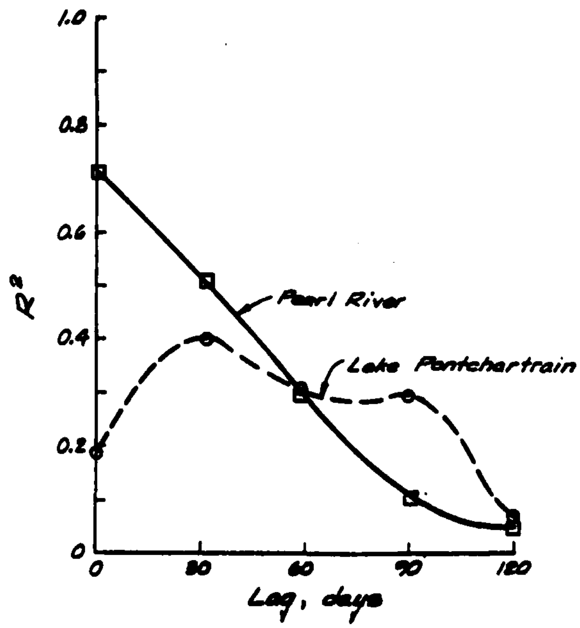


Figure 37. Cross-correlation between salinity and Pearl River and Lake Pontchartrain inflows using New Orleans District inflow and salinity data for weighting purposes

compared with each other and the relative influence of preceding month's flows could be determined. This influence assisted in recognizing and selecting the salient variables according to the flow and month for Lake Pontchartrain and the Pearl River flows.

48. Weighting was done to express the relative importance of each month's flows. Multiplying each month's flow by its respective weight (present month, last month, etc.) made the lagged variables more realistically delineated in the regression models even if their effect was small. Weights Wt were calculated by

$$\mathrm{Wt\ (LPi)} = \frac{\mathrm{R^{**}2\ (LPi)}}{\sum_{i=1}^{n} \mathrm{R^{**}2\ (LPi)}} \tag{1}$$

$$\mathrm{Wt\ (Pi)} = \frac{\mathrm{R^{**}2\ (Pi)}}{\sum_{i=1}^{n} \mathrm{R^{**}2\ (Pi)}} \tag{2}$$

where

R**2 (LPi) = Coefficient of correlation for Lake Pontchartrain lagged from 0 to 4

R**2 (Pi) = Coefficient of correlation for Pearl River lagged from 0 to 4

Values of the weights are given in Table 5 and plotted in Figures 35-37.

49. The data were normalized by dividing the Pearl River and Lake Pontchartrain monthly flows by their annual average daily flows. The following illustrates the normalizing procedure used:

$$\mathrm{POP} = \frac{\mathrm{PO}}{\mathrm{PAV}} \tag{3}$$

$$\mathrm{LPOP} = \frac{\mathrm{LPO}}{\mathrm{LPAV}} \tag{4}$$

where

POP = current monthly Pearl River flow primed

PO = Pearl River flow, current month

PAV = Pearl River average flow = 10,000 cfs

Table 5

Calculated Regression

Pearl River	R**2	Wt	Lake Pontchartrain	R**2	Wt
		Weights for Station 4			
PO	0.60	0.24	LPO	0.48	0.19
P1	0.91	0.36	LP1	0.90	0.36
P2	0.56	0.22	LP2	0.59	0.23
P3	0.32	0.13	LP3	0.38	0.15
P4	0.10	0.04	LP4	0.17	0.07
		Weights for Stations 5 and 8			
PO	0.41	0.22	LPO	0.33	0.17
P1	0.70	0.37	LP1	0.75	0.40
P2	0.48	0.25	LP2	0.47	0.25
P3	0.20	0.11	LP3	0.22	0.12
P4	0.09	0.05	LP4	0.11	0.06
		Coefficients for LMN Data			
PO	0.70	0.42	LPO	0.20	0.17
P1	0.50	0.30	LP1	0.40	0.33
P2	0.30	0.18	LP2	0.30	0.25
P3	0.10	0.06	LP3	0.30	0.25
P4	0.05	0.03	LP4	0.08	0.07

Note: P1 = Pearl River flow lagged 1 month
P2 = Pearl River flow lagged 2 months
P3 = Pearl River flow lagged 3 months
P4 = Pearl River flow lagged 4 months
LP1 = Lake Pontchartrain flow lagged 1 month
LP2 = Lake Pontchartrain flow lagged 2 months
LP3 = Lake Pontchartrain flow lagged 3 months
LP4 = Lake Pontchartrain flow lagged 4 months

LPOP = current monthly Lake Pontchartrain flow primed

LPO = Lake Pontchartrain flow, current month

LPAV = Lake Pontchartrain average flow = 3,800 cfs

Actual Regression Models Used

50. The New Orleans District and WES data were used in the development of several more regression models using flows weighted and normalized according to the techniques described previously. The models were also fit to weighted or normalized data only, or data not weighted or normalized at all. Tables 6-10 present the results of the additional regressions.

51. As can be seen in the tables, weighting and normalizing produce more exact results than not weighting or normalizing. The weighted and normalized regression equations yielded an intercept value closer to Gulf salinity, a more reasonable intercept value than those produced by the regression equations that were not weighted or normalized. While a reasonable intercept value of near Gulf salinity (the source salinity) is not essential for the range of target salinities (8-17 ppt), it provides some assurance that the regression function remains well-behaved at all salinity values. All of the equations that were weighted or normalized produced realistic negative coefficients for the flow terms. This result is reasonable because it states that as the flow increases, the salinity decreases. Equations 4b and 4c (Table 7) produced negative and positive coefficients, thereby invalidating them as credible regression equations. Use of these equations should be avoided, but they are presented here to show the range of results obtained from the regressions.

52. Equation 2a (Table 6) yielded the highest coefficient of correlation (0.86) for the New Orleans District data.

53. Equation 5a (Table 7) yielded the highest coefficient of correlation (0.71) for stations 5 and 8. The standard error was ±2.5 ppt.

54. Equation 8a (Table 8) yielded the highest coefficient of correlation (0.92) for station 4.

55. The New Orleans District data set was combined with the WES data sets for station 4 and for stations 5 and 8. The resulting data sets consisted of 37 points for the New Orleans District data and stations 5 and 8 combined, and 30 points for the New Orleans District data and station 4

Table 6

Regressions Using New Orleans District Data and Weights from New Orleans District Data

---

Weighted and Normalized

1a. $SALN = B1 * \ln (0.23 * POP) + B2 * \ln (0.26 * LP1P) + I$

Regression Results

$B1 = -3.50 \quad I = 22.05$

$B2 = -1.16 \quad r^2 = 0.72$

Normalized Only

1b. $SALN = B1 * \ln (POP) + B2 * \ln (LP1P) + I$

Regression Results

$B1 = -3.50 \quad I = 28.74$

$B2 = -1.16 \quad r^2 = 0.72$

Not Weighted or Normalized

1c. $SALN = B1 * \ln (PO) + B2 * \ln (LP1) + I$

Regression Results

$B1 = -3.49 \quad I = 70.48$

$B2 = -1.16 \quad r^2 = 0.72$

(Continued)

Note: P1P = Pearl River flow primed, lagged 1 month
P2P = Pearl River flow primed, lagged 2 months
P3P = Pearl River flow primed, lagged 3 months
P4P = Pearl River flow primed, lagged 4 months
LP1P = Lake Pontchartrain flow primed, lagged 1 month
LP2P = Lake Pontchartrain flow primed, lagged 2 months
LP3P = Lake Pontchartrain flow primed, lagged 3 months
LP4P = Lake Pontchartrain flow primed, lagged 4 months

(Sheet 1 of 3)

Table 6 (Continued))

Weighted and Normalized

2a. SALN = B1 * ln (0.23 * POP) + B2 * ln [(0.19 * LPOP) + (0.26 * LP1P) + (0.20 * LP2P) + (0.22 * P2P) + (0.13 * P3P)] + I

Regression Results

B1 = -2.69   I = 31.52

B2 = -3.73 r^2 = 0.86

Normalized only

2b. SALN = B1 * ln (POP) + B2 * ln [(LPOP) + (LP1P) + (LP2P) + (P2P) + (P3P)] + I

Regression Results

B1 = -2.88   I = 41.33

B2 = -3.57 r^2 = 0.86

Not Weighted or Normalized

2c. SALN = B1 * ln (PO) + B2 * ln (LPO + LP1 + LP2 + P2 + P3) + I

Regression Results

B1 = -3.38   I = 93.42

B2 = -2.71 r^2 = 0.86

(Continued)

(Sheet 2 of 3)

Table 6 (Concluded)

<u>Weighted and Normalized</u>

3a. SALN = B1 * ln [(0.23 * POP) + (0.28 * P1P)] + B2 * ln [(0.19 * LPOP) + (0.26 * LP1P) + (0.22 * P2P) + (0.13 * P3P)] + I

Regression Results

B1 = -2.55 I = 30.67

B2 = -3.10 r^2 = 0.81

<u>Normalized Only</u>

3b. SALN = B1 * ln [(POP) + (P1P)] + B2 * ln [(LPOP) + (LP1P) + (P2P) + (P3P)] + I

Regression Results

B1 = -2.91 I = 38.77

B2 = -2.72 r^2 = 0.82

<u>Not Weighted or Normalized</u>

3c. SALN = B1 * ln (PO + P1) + B2 * ln (LPO + LP1 + P2 + P3) + I

Regression Results

B1 = -3.21 I = 81.39

B2 = -1.62 r^2 = 0.80

(Sheet 3 of 3)

Table 7

Regressions Using WES Data and Weights from Stations 5 and 8

Weighted and Normalized

4a. SALN = B1 * ln [(0.22 * POP) + (0.37 * P1P) + (0.25 * P2P)]
+ B2 * ln [(0.17 * LPOP) + (0.40 * LP1P) + (0.25 * LP2P)] + I

Regression Results

B1 = -3.14 I = 23.27

B2 = -1.23 r^2 = 0.69

Normalized Only

4b. SALN = B1 * ln (POP + P1P + P2P) + B2 * ln (LPOP + LP1P + LP2P) + I

Regression Results

B1 = -10.26 I = 23.26

B2 = +6.86 r^2 = 0.69

Not Weighted or Normalized

4c. SALN = B1 * ln (P0 + P1 + P2) + B2 * ln (LP0 + LP1 + LP2) + I

Regression Results

B1 = -10.26 I = 61.24

B2 = +6.86 r^2 = 0.69

(Continued)

(Sheet 1 of 3)

Table 7 (Continued)

Weighted and Normalized

5a. SALN = B1 * ln [(0.22 * POP) + (0.37 * P1P)] + B2 * ln [(0.40 * LP1P) + (0.25 * LP2P) + (0.12 * LP3P)] + I

Regression Results

B1 = -1.75 I = 23.44

B2 = -2.85 r^2 = 0.71

Normalized Only

5b. SALN = B1 * ln (POP + P1P) + B2 * ln (LP1P + LP2P + LP3P) + I

Regression Results

B1 = -2.51 I = 28.68

B2 = -2.03 r^2 = 0.67

Not Weighted or Normalized

5c. SALN = B1 * ln (PO + P1) + B2 * ln (LP1 + LP2 + LP3) + I

Regression Results

B1 = -2.51 I = 68.51

B2 = -2.03 r^2 = 0.67

(Continued)

(Sheet 2 of 3)

Table 7 (Concluded)

Weighted and Normalized

6a. SALN = B1 * ln (0.22 * POP) + B2 * ln [(0.40 * LP1P) + (0.25 * LP2P) + (0.12 * LP3P)] + I

Regression Results

B1 = -0.74 I = 23.77

B2 = -4.04 r^2 = 0.70

Normalized Only

6b. SALN = B1 * ln (POP) + B2 * ln (LP1P + LP2P + LP3P) + I

Regression Results

B1 = -1.38 I = 68.51

B2 = -3.33 r^2 = 0.63

Not Weighted or Normalized

6c. SALN = B1 * ln (PO) + B2 * ln (LP1 + LP2 + LP3) + I

Regression Results

B1 = -1.38 I = 69.39

B2 = -3.33 r^2 = 0.63

(Sheet 3 of 3)

Table 8

Regressions Using WES Data and Weights from Station 4

Weighted and Normalized

7a. SALN = B1 * ln (0.36 * P1P) + B2 * ln (0.36 * LP1P) + I

Regression Results

B1 = -4.42 I = 22.21

B2 = -1.33 r^2 = 0.92

Normalized Only

7b. SALN = B1 * ln (P1P) + B2 * ln (LP1P) + I

Regression Results

B1 = -4.42 I = 28.37

B2 = -1.33 r^2 = -0.92

Not Weighted or Normalized

7c. SALN = B1 * ln (P1) + B2 * ln (LP1) + I

Regression Results

B1 = -4.42 I = 80.00

B2 = -1.33 r^2 = 0.92

(Continued)

(Sheet 1 of 3)

Table 8 (Continued)

Weighted and Normalized

8a. $SALN = B1 * \ln [(0.24 * POP) + (0.36 * P1P)] + B2 * \ln [(0.36 * LP1P) + (0.23 * LP2P)] + I$

Regression Results

$B1 = -4.32 \qquad I = 26.90$

$B2 = -1.82 \qquad r^2 = 0.92$

Normalized Only

8b. $SALN = B1 * \ln (POP + P1P) + B2 * \ln (LP1P + LP2P) + I$

Regression Results

$B1 = -3.87 \qquad I = 34.92$

$B2 = -2.40 \qquad r^2 = 0.91$

Not Weighted or Normalized

8c. $SALN = B1 * \ln (PO + P1) + B2 * \ln (LP1 + LP2) + I$

Regression Results

$B1 = -3.87 \qquad I = 90.39$

$B2 = -2.40 \qquad r^2 = 0.91$

(Continued)

Table 8 (Concluded)

Weighted and Normalized

9a. $SALN = B1 * \ln(0.24 * POP) + B2 * \ln(0.36 * LP1P) + I$

Regression Results

B1 = -0.72	I = 24.33
B2 = -5.45	r^2 = 0.91

Normalized Only

9b. $SALN = B1 * \ln(POP) + B2 * \ln(LP1P) + I$

Regression Results

B1 = -0.72	I = 30.93
B2 = -5.45	r^2 = 0.91

Not Weighted or Normalized

9c. $SALN = B1 * \ln(PO) + B2 * \ln(LP1) + I$

Regression Results

B1 = -0.72	I = 82.50
B2 = -5.45	r^2 = 0.91

(Sheet 3 of 3)

Table 9

Regressions Using Combined New Orleans District and WES Data for Stations 5 and 8

Weighted and Normalized

10a. SALN = B1 * ln [(0.22 * POP) + (0.37 * P1P)] + B2 * ln [(0.40 * LP1P) + (0.25 * LP2P) + (0.12 * LP3P)] + I

Regression Results

B1 = -2.42	I = 35.52
B2 = -3.78	r^2 = 0.52

Normalized Only

10b. SALN = B1 * ln (POP + P1P) + B2 * ln (LP1P + LP2P + LP3P) + I

Regression Results

B1 = -3.03	I = 43.37
B2 = -3.17	r^2 = 0.50

Not Weighted or Normalized

10c. SALN = B1 * ln (PO + P1) + B2 * ln (LP1 + LP2 + LP3) + I

Regression Results

B1 = -3.03	I = 97.40
B2 = -3.17	r^2 = 0.50

Table 10

Regressions Using Combined New Orleans District and WES Data for Station 4

Weighted and Normalized

11a. SALN = B1 * ln [(0.24 * P0P) + (0.36 * P1P)] + B2 * ln [(0.36 * LP1P) + (0.23 * LP2P)] + I

Regression Results

B1 = -4.86   I = 39.11

B2 = -2.78 r^2 = 0.71

Normalized Only

11b. SALN = B1 * ln (P0P + P1P) + B2 * ln (LP1P + LP2P) + I

Regression Results

B1 = -5.15   I = 48.75

B2 = -2.59 r^2 = 0.72

Not Weighted or Normalized

11c. SALN = B1 * ln (P0 + P1) + B2 * ln (LP1 + LP2) + I

Regression Results

B1 = -5.15   I = 117.53

B2 = -2.59 r^2 = 0.72

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combined. As a result of this, the r^2 value decreased from 0.71 for Equation 5a to 0.52 for Equation 10a (Table 9). The resulting data set was one that consisted of more data points but had the inherent problem of containing more noise. This produced lower correlation coefficients from regression analysis, but the smaller correlation coefficient does not indicate that the model (Equations 10 and 11) is inferior to the others.

Spectral Analysis Results

56. Results of spectral analysis that was performed on the Bay Boudreau data are given in Appendix B. Daily data values were used in this portion of the study. The spectral results corroborate the regression analysis results by showing the relative importance of the flows from previous months, but also show the importance of three other factors--temperature, water level, and wind. All factors were found to create large forcings with respect to the intended salt response, although not at all frequencies. For instance, short bursts of flow from Lake Pontchartrain were found not to cause a significant salinty reduction.

PART V: CALCULATED DIVERSION FLOWS

57. The purpose of the proposed diversion of freshwater flow into Lake Pontchartrain is to improve salinity conditions for finfish and shellfish. The feasibility study (USAED, New Orleans, 1984) identified maximum freshwater diversions through the proposed structure and an optimum seasonal distribution of salinities (see paragraph 2). This distribution was used along with the statistical regression models described in the previous section to forecast diversion amounts and scheduling. Equations 5a and 10a were selected for forecasting.

58. Monthly natural flow levels corresponding to the 50 percent frequency of occurrence were used as a base. The difference between the required flows necessary to achieve the target salinities at Treasure Pass and the 50 percent Lake Pontchartrain tributaries flow was the required diversion flow.

59. The target salinities were multiplied by 0.77 or 1.0 in order to convert them to station 5 and 8 salinities or Treasure Pass salinities, respectively (Appendix C).

60. The diversion flows were calculated as follows:

a. The equation (5a or 10a) was rearranged to express the previous month's Lake Pontchartrain flow as a function of the target salinity, previous month's Lake Pontchartrain flows, and previous month's Pearl River flows.

b. Base riverflows for both sources were assumed to be the mean monthly natural flows.

c. October through December natural Lake Pontchartrain flows were assumed to be the total Lake Pontchartrain flows (natural plus diversion) for those months in order to begin the calculations. Using the rearranged equation, the total Lake Pontchartrain January flow required to obtain the February target salinity was calculated. The January total Lake Pontchartrain flow was then set either to the calculated total flow requirement or the natural flow, whichever was higher.

d. The Lake Pontchartrain flow for the next month was then calculated by the same process.

e. Step d was repeated for each successive month until the calculations converged. All calculations converged within about 3 years of month-by-month calculations, repeating the 50 percent flows each year.

f. The converged total flow requirement minus the natural 50 percent flow from Lake Pontchartrain was taken to be the diversion flow for each month. The diversion flow was converted to daily flow rate by dividing by the number of days in the month.

g. The actual salinities resulting from the natural Pearl River and Lake Pontchartrain flows plus diversion amount was calculated by the original equation to confirm the diversion flow and to find if overfreshening occurred at any time.

61. Table 11 shows the diversions calculated by Equation 5a. The target salinity shown in the second column is that which is to be obtained from the diversion flows. The 50 percent (mean) flows are given in columns 3 and 4. Column 5 shows the calculated Lake Pontchartrain flow from the regression equation. Column 6 shows the postdiversion flow from Lake Pontchartrain. Columns 7 and 8 show the actual diversions needed for the target salinity. Column 9 shows the actual calculated salinity from the regression equation using the diversion plus natural flows. Figure 38 illustrates the salinities shown in Table 11. As can be seen, the target salinities are either approximately equal to or higher than the calculated salinities. Figure 39 shows required diversions by month.

62. Tables 12 and 13, respectively, show the diversions calculated when the standard errors of -2.5 ppt and +2.5 ppt obtained from the regression analysis for Equation 5a are added to the target salinities. They illustrate the range of diversion flows that could be required based on the 1986-1987 data set. The maximum diversion flow of 20,968 cfs occurs when -2.5 ppt is added to target salinities. When +2.5 ppt is added to the target salinities, the maximum diversion flow is 177 cfs and diversion occurs in only 1 month. Figure 40 shows target salinities, actual salinities, and modified salinities according to month. It shows the target salinities, calculated salinity from Equation 5a, and target salinity plus -2.5 ppt fairly close to one another during various diversion flows. This shows that in periods of high diversion flows these salinities vary little from one another and can be reached. Adding +2.5 ppt to the targets increases them to the point that, with Equation 5a, diversion is not required. Figure 41 shows the range of diversion flows for the target, +2.5 ppt, and -2.5 ppt target salinities.

63. Table 14 shows diversions for Equation 10a. Equation 10a, which used the combined data set consisting of New Orleans District and WES data, yielded results which were similar to the New Orleans District results. When compared to the maximum possible diversions for the proposed structure (paragraph 2), only 2 months, October and September, showed a need for diversion

Table 11

Lake Pontchartrain Diversions to Achieve Target Salinities Using Equation 5a

Month (1)	Target Salinity ppt (2)	Mean Flow, cfs-days: Pearl River (3)	Mean Flow, cfs-days: Lake Pontchartrain (4)	Lake Pontchartrain Flow, cfs-days: Calculated (5)	Lake Pontchartrain Flow, cfs-days: Post-diversion (6)	Needed Diversion Flow cfs-days (7)	Diversion Flow cfs (8)	Actual Salinity ppt (9)
Oct	17.0	63,457	36,809	117,560	117,560	80,756	2,605	17.0
Nov	16.0	79,530	38,562	43,623	43,623	5,061	169	16.0
Dec	16.0	165,509	95,936	36,330	95,936	0	0	16.0
Jan	16.0	297,662	131,967	47,439	131,970	0	0	14.3
Feb	14.0	505,680	147,868	214,420	214,420	66,553	2,377	12.0
Mar	9.5	592,720	169,911	310,920	310,920	141,009	4,549	9.5
Apr	8.0	465,300	127,950	319,900	319,900	191,948	6,398	8.0
May	8.0	312,790	90,328	-57,210	90,328	0	0	8.0
Jun	12.5	125,340	51,273	166,600	16,660	115,322	3,844	10.7
Jul	13.0	109,182	53,150	26,152	53,150	0	0	13.0
Aug	16.0	86,552	46,544	54,140	54,140	7,596	245	15.4
Sep	17.0	71,640	41,607	102,310	102,310	60,705	2,024	17.0

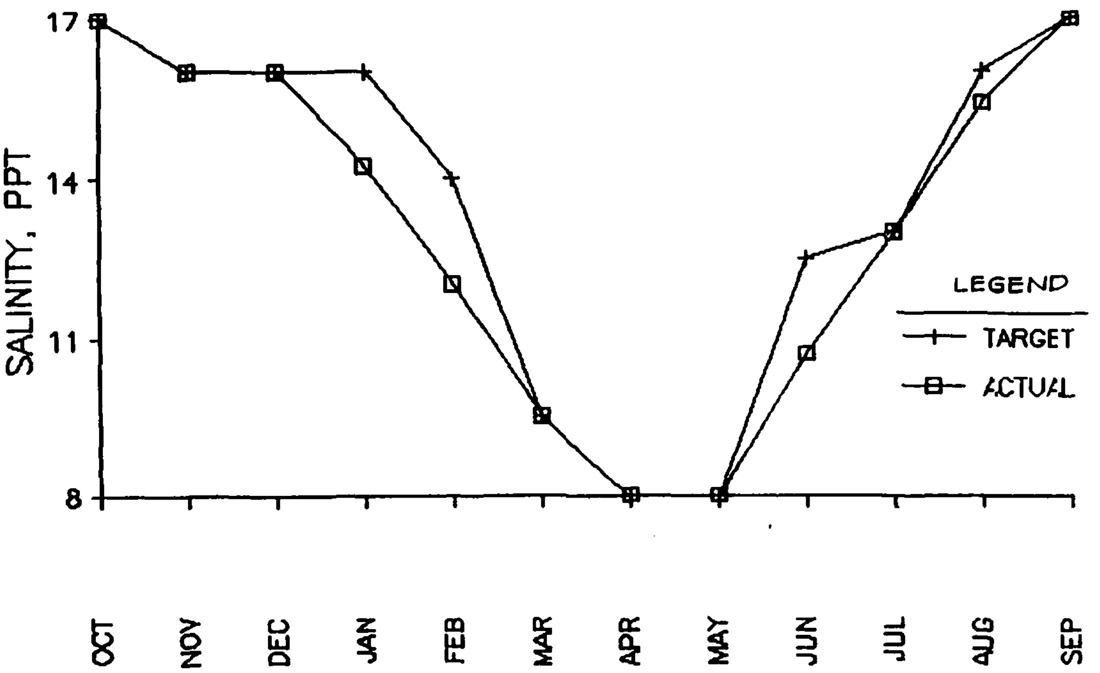

Figure 38. Target and actual salinities using Equation 5a

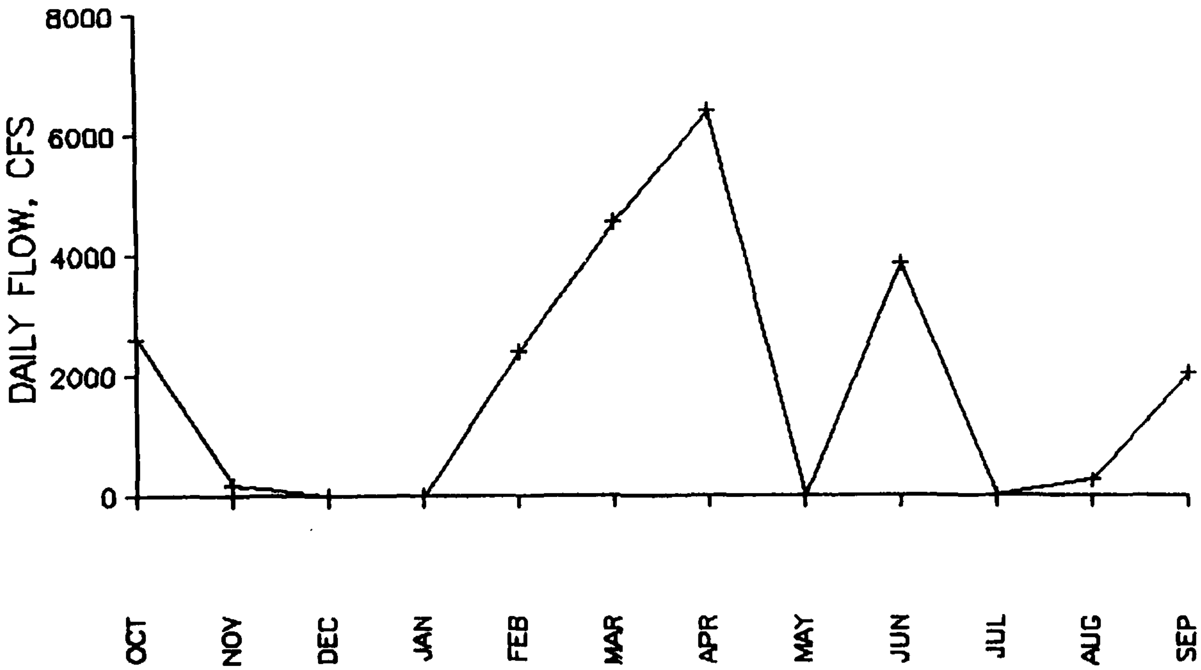

Figure 39. Daily diversion flow for the combined WES stations 5 and 8 calculated using Equation 5a

Table 12

Lake Pontchartrain Diversions to Achieve Target

-2.5 ppt Using Equation 5a

		Mean Flow, cfs-days		Lake Pontchartrain Flow, cfs-days				
Month (1)	Target* Salinity ppt (2)	Pearl River (3)	Lake Pontchartrain (4)	Calculated (5)	Post-diversion (6)	Needed Diversion Flow cfs-days (7)	Diversion Flow cfs (8)	Actual Salinity ppt (9)
Oct	17.0	63,457	36,809	270,620	270,620	233,814	7,542	17.0
Nov	16.0	79,530	38,562	109,760	109,760	71,193	2,373	16.0
Dec	16.0	165,509	95,936	87,900	95,936	0	0	16.0
Jan	16.0	297,662	131,967	196,780	196,780	64,813	2,091	15.9
Feb	14.0	505,680	147,868	631,220	631,220	483,348	17,262	14.0
Mar	9.5	592,720	169,911	711,320	711,320	541,408	17,465	9.5
Apr	8.0	465,300	127,950	759,680	759,680	629,026	20,968	8.0
May	8.0	312,790	90,328	-119,100	90,328	0	0	8.0
Jun	12.5	125,340	51,273	483,420	483,420	432,148	14,405	11.3
Jul	13.0	109,182	53,150	49,109	53,150	0	0	13.0
Aug	16.0	86,552	46,544	151,930	151,930	105,390	3,400	16.0
Sep	17.0	71,640	41,607	254,750	254,750	213,147	7,105	17.0

* Target modified by multiplying by 0.77 and subtracting standard error of 2.5 ppt.

Table 13

Lake Pontchartrain Diversions to Achieve Target

+2.5 ppt Using Equation 5a

Month (1)	Target* Salinity ppt (2)	Mean Flow, cfs-days: Pearl River (3)	Mean Flow, cfs-days: Lake Pontchartrain (4)	Lake Pontchartrain Flow, cfs-days: Calculated (5)	Lake Pontchartrain Flow, cfs-days: Post-diversion (6)	Needed Diversion Flow cfs-days (7)	Diversion Flow cfs (8)	Actual Salinity ppt (9)
Oct	17.0	63,457	36,809	42,287	42,287	5,478	177	15.8
Nov	16.0	79,530	38,562	22,564	38,562	0	0	16.0
Dec	16.0	165,509	95,936	4,335	95,936	0	0	15.1
Jan	16.0	297,662	131,967	-21,410	131,970	0	0	11.7
Feb	14.0	505,680	147,868	24,207	147,870	0	0	8.8
Mar	9.5	592,720	169,911	69,529	169,910	0	0	7.1
Apr	8.0	465,300	127,950	90,092	127,950	0	0	6.5
May	8.0	312,790	90,328	-32,780	90,328	0	0	7.5
Jun	12.5	125,340	51,273	37,856	51,273	0	0	9.5
Jul	13.0	109,182	53,150	6,314	53,150	0	0	12.6
Aug	16.0	86,552	46,544	8,524	46,544	0	0	14.0
Sep	17.0	71,640	41,607	18,229	41,607	0	0	15.1

* Target modified by multiplying by 0.77 and adding standard error of 2.5 ppt.

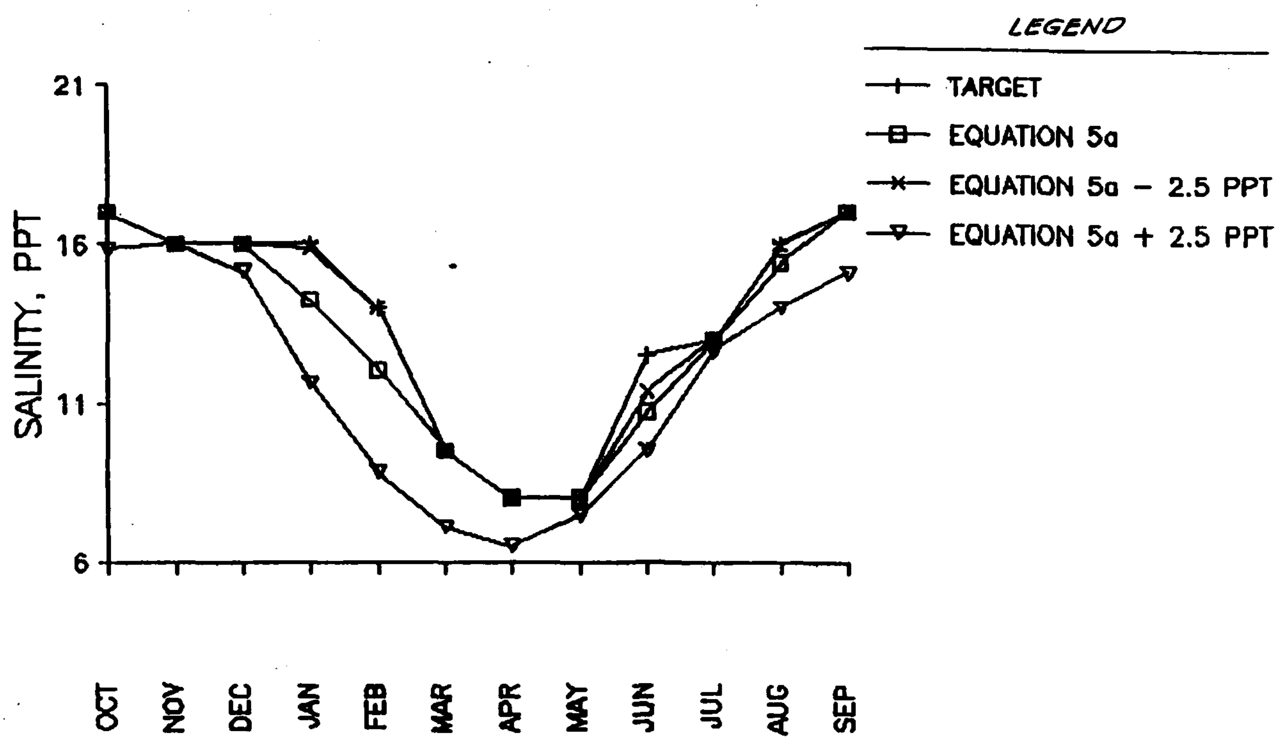

Figure 40. Adjusted and target salinities according to month calculated by Equation 5a

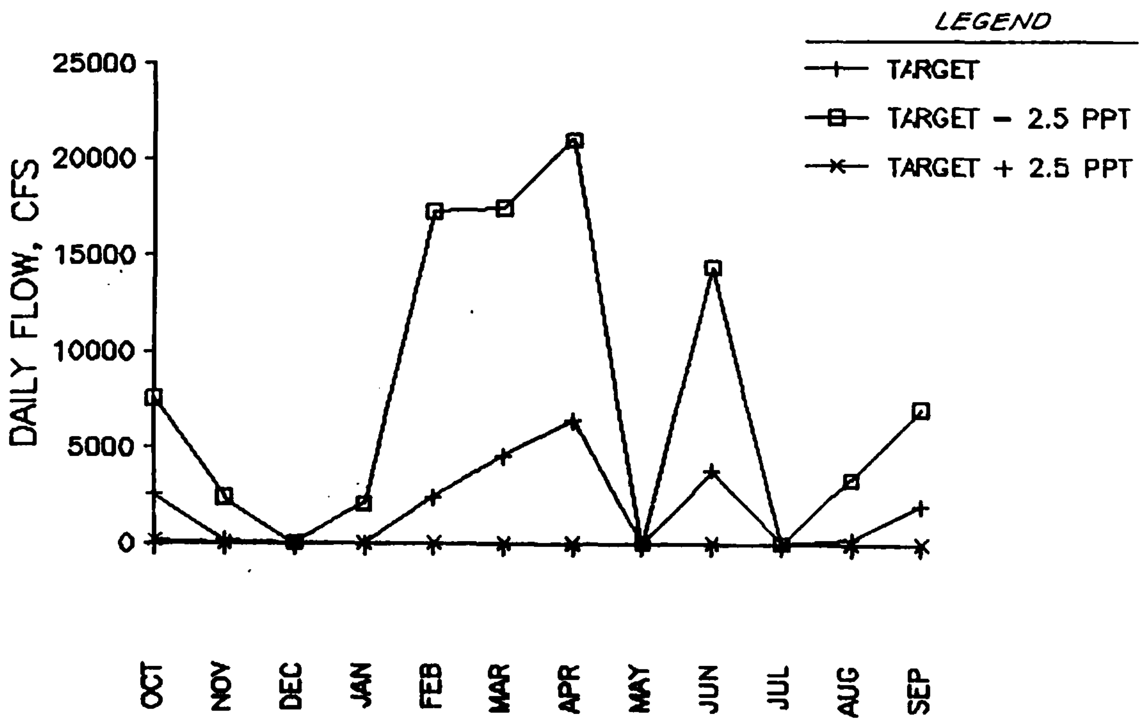

Figure 41. Range of diversion flows for Equation 5a

Table 14

Lake Pontchartrain Diversions to Achieve Target Salinities Using Equation 10a

Month (1)	Target Salinity ppt (2)	Mean flow, cfs-days: Pearl River (3)	Mean flow, cfs-days: Lake Pontchartrain (4)	Lake Pontchartrain Flow cfs-days: Calculated (5)	Lake Pontchartrain Flow cfs-days: Post-diversion (6)	Needed Diversion Flow cfs-days (7)	Diversion Flow cfs (8)	Actual Diversion Flow, cfs (9)	Actual Salinity ppt (10)
Oct	17.0	63,457	36,809	379,800	379,800	342,995	11,064	8,150*	18.2
Nov	16.0	79,530	38,562	150,040	150,040	111,481	3,716	3,716	14.4
Dec	16.0	165,509	95,936	119,150	119,150	23,210	749	749	16.0
Jan	16.0	297,662	131,967	268,700	268,700	136,737	4,411	4,411	15.8
Feb	14.0	505,680	147,868	809,760	809,760	661,889	23,639	23,639	14.0
Mar	9.5	592,720	169,911	907,830	907,830	737,919	23,804	23,804	9.5
Apr	8.0	465,300	127,950	987,790	987,790	859,842	28,661	28,661	8.0
May	8.0	312,790	90,328	-12,710	90,328	0	0	0	8.0
Jun	12.5	125,340	51,273	700,380	700,380	649,104	21,637	21,637	11.6
Jul	13.0	109,182	53,150	65,881	65,881	12,731	424	424	13.0
Aug	16.0	86,552	46,544	217,140	217,140	170,599	5,503	5,503	16.0
Sep	17.0	71,640	41,607	365,550	365,550	323,943	10,798	7,600*	17.0

* Actual flow limited to maximum possible monthly diversion (see paragraph 2).

flows greater than possible flows. For those 2 months, the maximum possible diversion was used to calculate actual salinities. The maximum diversion flow calculated by Equation 10a was 28,661 cfs, very close to a design diversion flow of 30,000 cfs calculated by the New Orleans District. Figures 42 and 43 display salinity and diversion flows, respectively, by month for Equation 10a.

64. Figure 44 compares the salinities versus Lake Pontchartrain flows (as expressed by the flows in the regression formula) from the combined data with those calculated by Equation 10a. As can be seen, the combined data set actual flows are lower than those calculated as needed by Equation 10a. This demonstrates the need for caution in using these results, since the system may behave differently at the elevated diversion flows. This could make the regression results unreliable predictors of salinity response as discussed in paragraph 10.

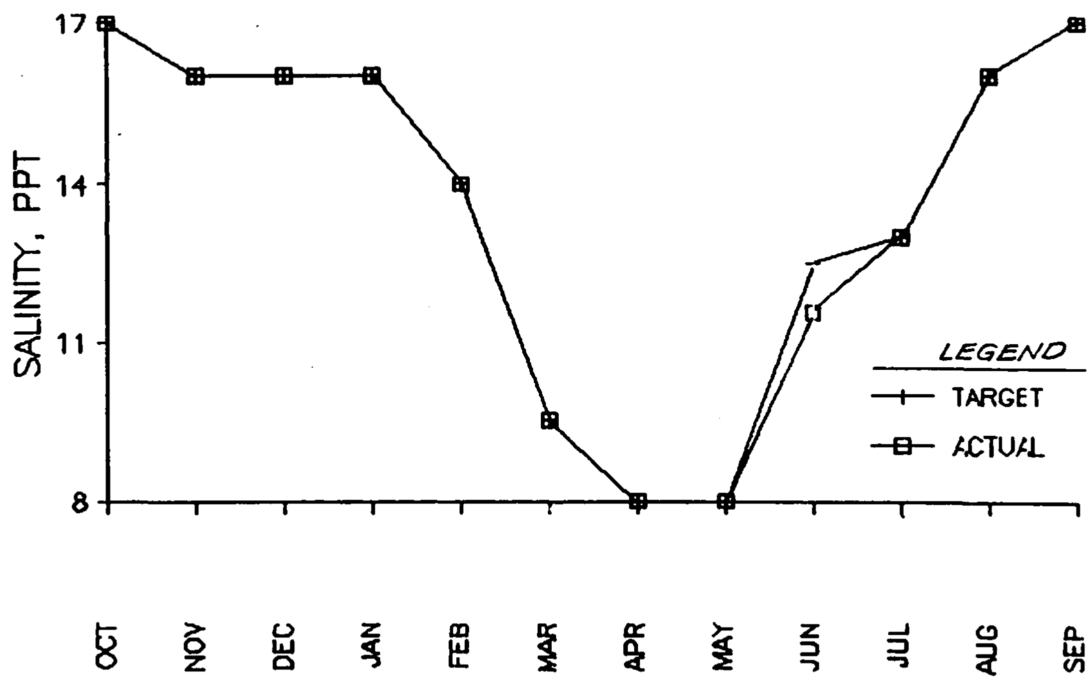

Figure 42. Salinity by month for Equation 10a

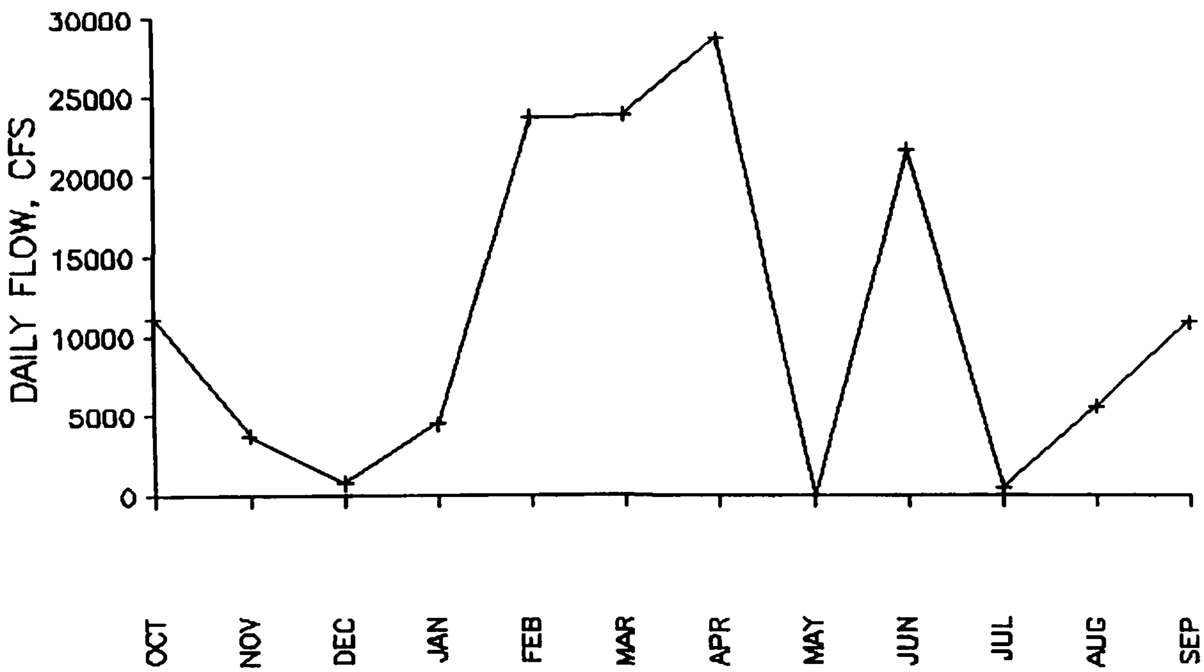

Figure 43. Diversion flow by month for Equation 10a

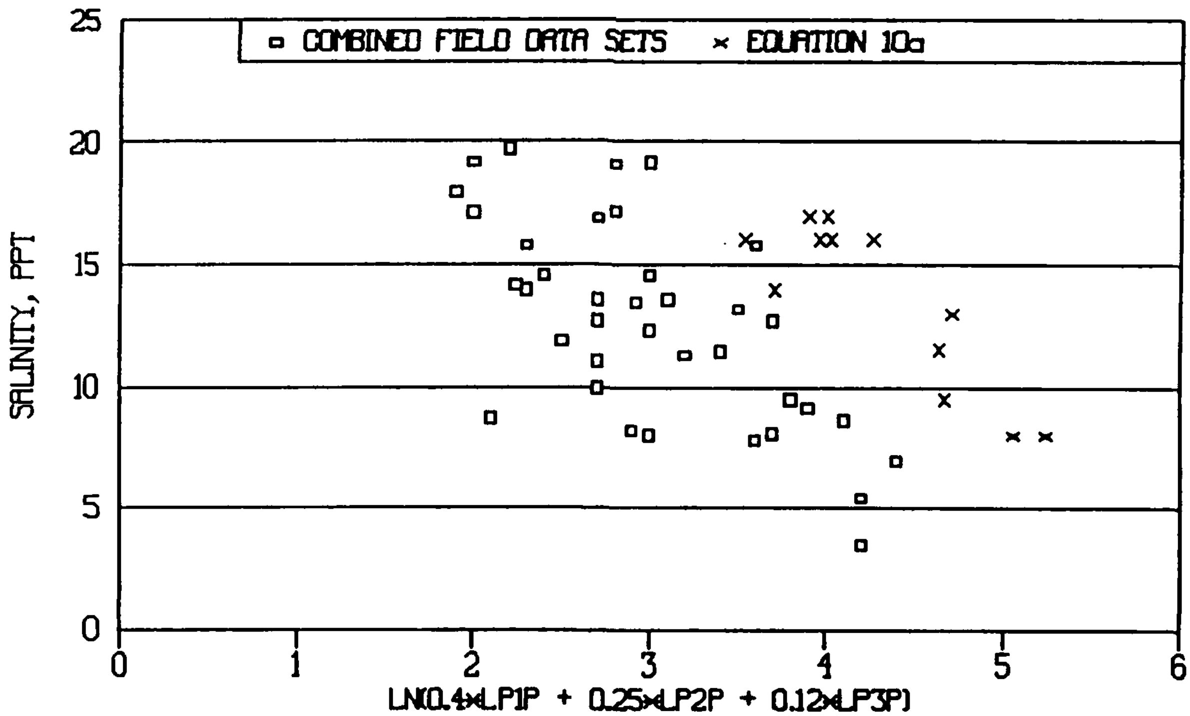

Figure 44. Salinity versus Lake Pontchartrain flows using the combined data versus Equation 10a

PART VI: CONCLUSIONS

65. Field measurements and analyses were used to predict diversion flows required to achieve monthly salinity target values in the Biloxi marshes. The study assumed that the marsh system responds consistently and its response will not be altered by human activities or natural changes.

66. Field measurements for 1986-1987 have indicated the following:

a. Salinities in the marshes increased generally from north to south and east to west. Salinities in the northern portion of Bay Boudreau (station 28) were 1 to 5 ppt lower than in the southern portion (station 23). Station 5s and 8 salinities averaged 77 percent of the Bay Boudreau averaged salinities.

b. At stations 5 and 8, seasonal salinity fluctuations were ±2 to 3 ppt about the annual cycle, and total salinity varied annually from a minimum of about 3 ppt to a maximum of about 19 ppt.

c. Salt flux calculations showed large variability in both direction and magnitude with time, location, and depth.

d. Drogue paths indicated that water movement can be the result of an overall circulation pattern or local mixing zone.

67. Regression models predicted a wide range of maximum required diversion flows. The maximum daily diversion rate according to WES regression models on the 1986-1987 WES data set alone was 5,000-6,500 cfs for a target factor of 0.77 (paragraph 3 in Appendix C, Table 11 in main text, and Tables C3-C7, Appendix C). This diversion rate is significantly lower than the 30,000 cfs predicted by the original LMN model (Table C1); however, the lower rate should not be used for design purposes. The regression models on which the 5,000- to 6,500-cfs predictions were made were not consistent with the New Orleans District data set. By substituting a target factor of 0.25 for the same conditions, the models indicated that the maximum monthly diversion rate was 28,000 cfs (Table C9). When the root mean square error (2.5 ppt) of Equation 5a (see Table 7) was subtracted from the salinity targets, the maximum monthly diversion predicted was just under 21,000 cfs (Table 12). Thus, design for the higher diversion flows compensates for the calculated uncertainty in the regression model.

68. Analyses of the combined WES and New Orleans District data sets produced models with greater average error than was produced by the analyses of individual data sets, but which are considered more reliable than any of the models based on only one data set. While the WES data set was more

intensive in time, the New Orleans District data set covered a broader range of flow conditions. Predicted maximum monthly diversion rates using Equation 10a (Table 9) were just under 30,000 cfs (Table 14). The standard error on these estimates was over 4 ppt, indicating that much larger diversions could be required in some years to compensate for the uncertainty in that regression model.

69. Results indicated that diversion flows will have to be programed well in advance, and therefore will not be effective in adjusting short-term (1-2 months) vagaries in freshwater conditions.

70. Results from models using longer system memory (larger lags) predicted slightly higher required diversions.

71. Spectral analysis indicates that, in addition to freshwater inflow and precipitation, temperature, water level, and east-west components of wind affect salinities appreciably and may have contributed to uncertainty in the regression.

72. The data analyses showed that the 30,000-cfs maximum diversion predicted by the New Orleans District data and regression model will be sufficient to freshen the Bay Boudreau area to target salinities on average during a median flow year, given the assumptions and limitations described in paragraph 10. Such a diversion may also be sufficient for a year with less than median inflow, depending on other environmental conditions.

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APPENDIX A: DATA TABLES AND FIGURES FOR NINE ROUTINE SURVEYS

1. The following data tables (Tables A1-A7) and corresponding data figures (Figures A1-A7) are presented here to document changes in salinity mentioned in the text.

2. Contours of salinity ratio (salinity divided by salinity at station 8) have been drawn on the figures. The data density does not warrant undue confidence in these contours, but in the aggregate, they do help to display some of the circulation patterns contributing to salinity distribution.

The data listed in the facing table are also displayed in the figure following.

Table A1

Bay Boudreau Salinity Data

Data Taken 17-19 June 1986

Station Number	Salinity, ppt Bottom	Mean*
1	5.8	5.8
2	7.0	7.0
3	8.5	8.5
4	10.7	10.8
5	8.8	8.4
6	9.6	9.6
7	9.1	9.0
8	9.9	9.9
9	10.4	10.5
10	9.1	9.1
11	9.1	8.2
12	13.7	10.6
13	9.7	9.5
14	16.1	15.1
16	20.4	14.2
22	28.5	24.3
23	20.4	20.4
24	17.3	17.3
25	19.7	19.7
26	19.5	19.4
27	15.7	15.5
28	13.4	13.5
29	20.1	20.1
30	19.7	19.7
31	10.2	10.2
32	10.0	9.4
33	15.9	15.9
TG1	5.9	5.8
TG2	9.4	9.4
TG3	27.1	21.6
TG4	17.2	13.7
TG5	11.1	11.0
TG7	25.0	23.8

* Average of bottom, middepth, and surface values.

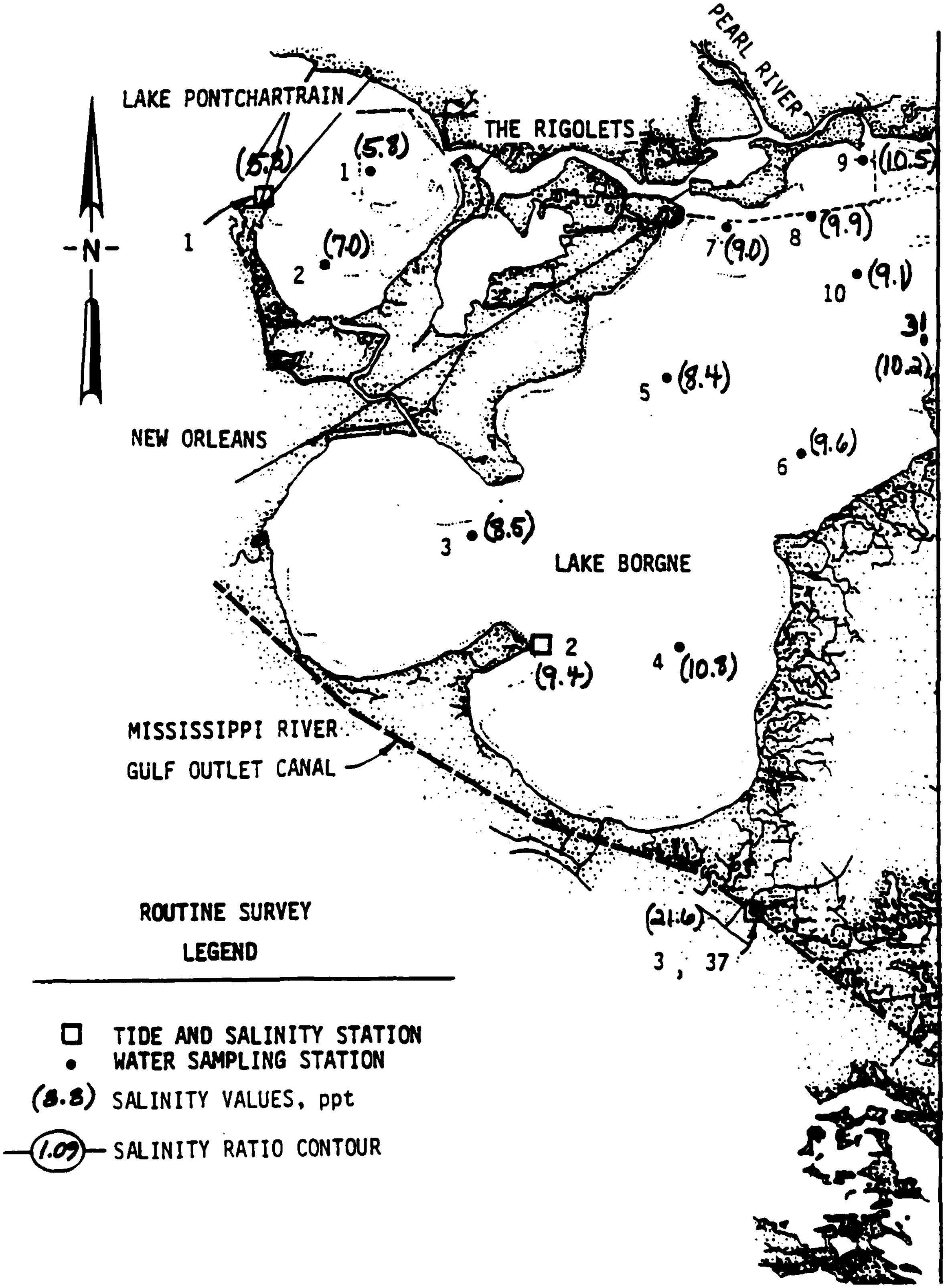

Figure A1. Bay Boudreau salinity data, 17-19 June 1986 (Continued)

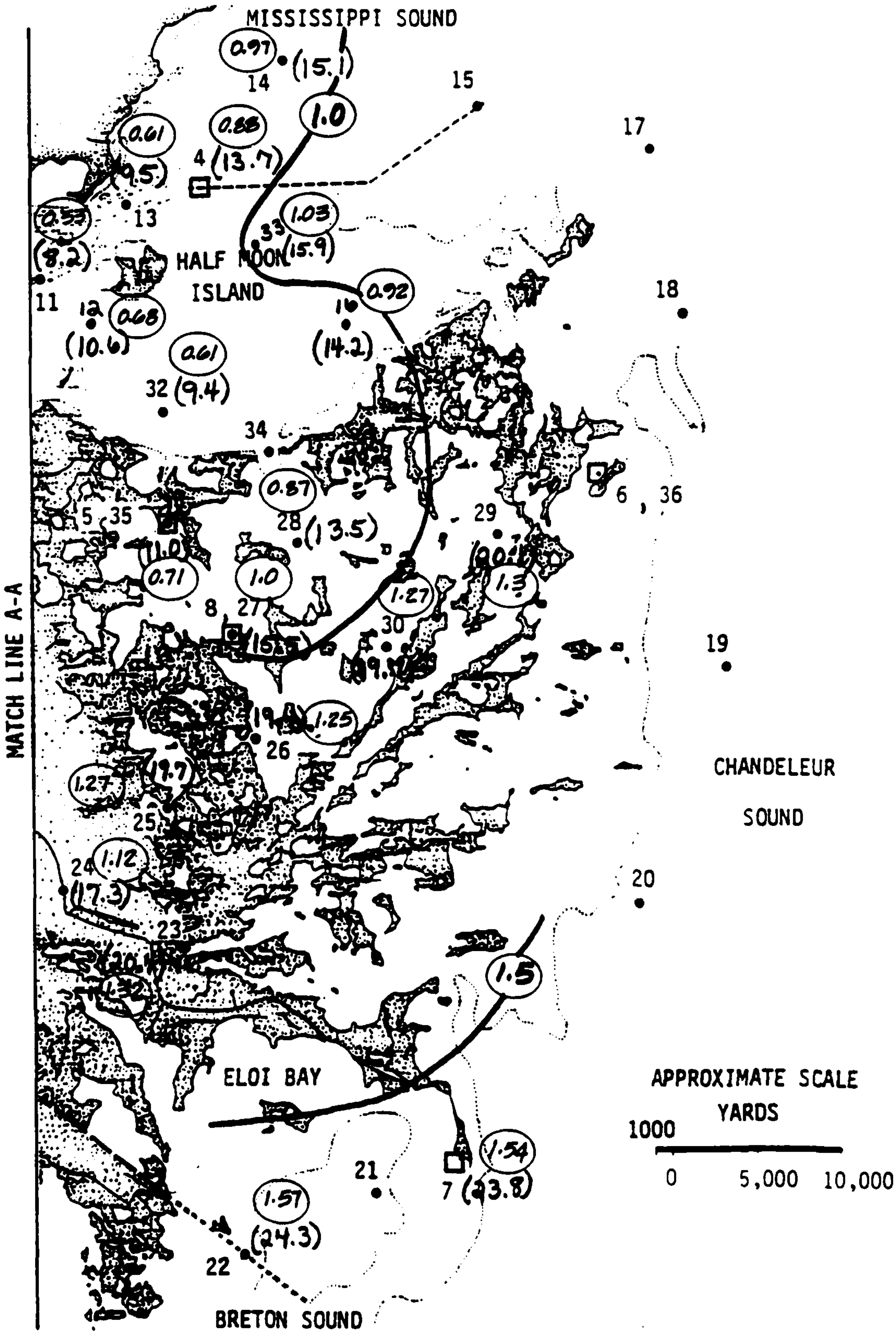

Figure A-1. (Concluded)

The data listed in the facing table are also displayed in the figure following.

Table A2

Bay Boudreau Salinity and Temperature Data

Data Taken 5-7 August 1986

Station Number	Salinity, ppt Bottom	Salinity, ppt Mean*	Temperature, °C Bottom	Temperature, °C Mean*
1	9.3	9.3	30.0	30.0
2	9.2	9.2	30.3	30.3
3	15.8	13.2	30.3	29.9
4	13.2	13.0	-	-
5	11.2	11.2	29.6	29.6
6	11.2	11.2	29.6	29.6
7	17.8	16.8	31.1	31.1
8	18.7	18.4	30.9	30.9
9	18.6	18.6	30.6	30.6
10	16.5	16.0	30.4	30.4
11	18.7	18.0	30.2	30.2
12	20.7	20.5	30.6	30.6
13	22.8	22.0	29.9	30.1
14	26.8	26.7	30.4	30.7
15	32.8	32.6	30.1	30.1
16	24.3	23.7	30.1	30.1
17	35.5	35.4	29.3	29.4
18	35.4	35.2	29.9	30.1
19	33.6	30.5	30.9	30.8
20	26.5	25.9	30.6	30.6
21	27.7	27.4	30.0	30.1
22	30.5	29.0	-	-
24	19.1	19.0	-	-
25	-	20.2	-	30.9
26	-	14.3	-	30.8
27	13.3	13.2	30.4	30.4
28	-	14.6	-	30.0
29	-	26.5	-	30.9
30	-	15.4	-	30.1
31	14.8	14.6	30.4	30.4
32	20.1	20.0	30.6	30.6
33	25.4	25.3	30.4	30.4
34	15.7	15.5	30.3	30.3
35	15.0	14.6	30.4	30.9
TG4	26.5	26.3	30.7	30.9
TG7	25.8	25.8	30.4	30.4

* Average of bottom, middepth, and surface values.

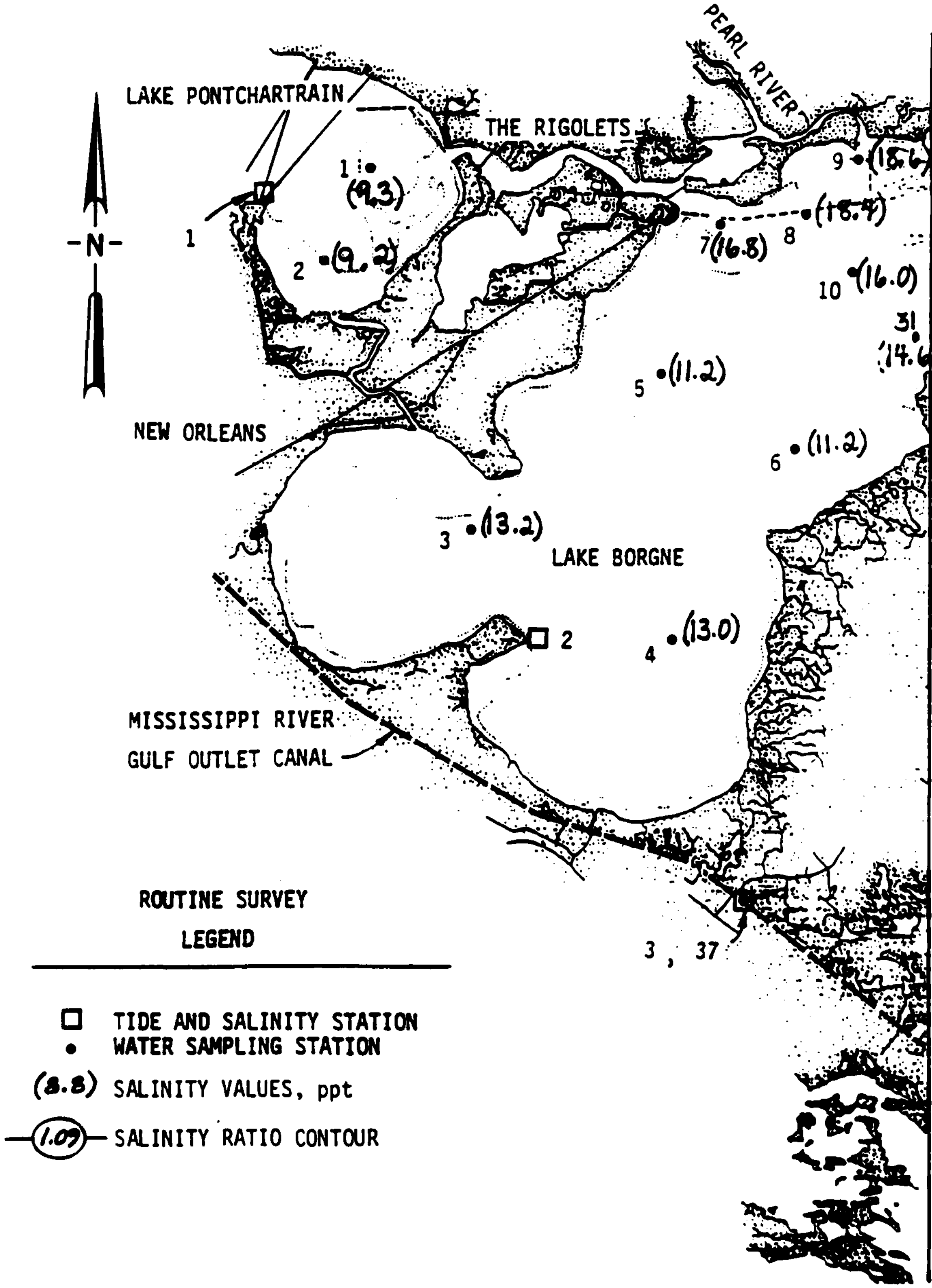

Figure A2. Bay Boudreau salinity data, 5-7 August 1986 (Continued)

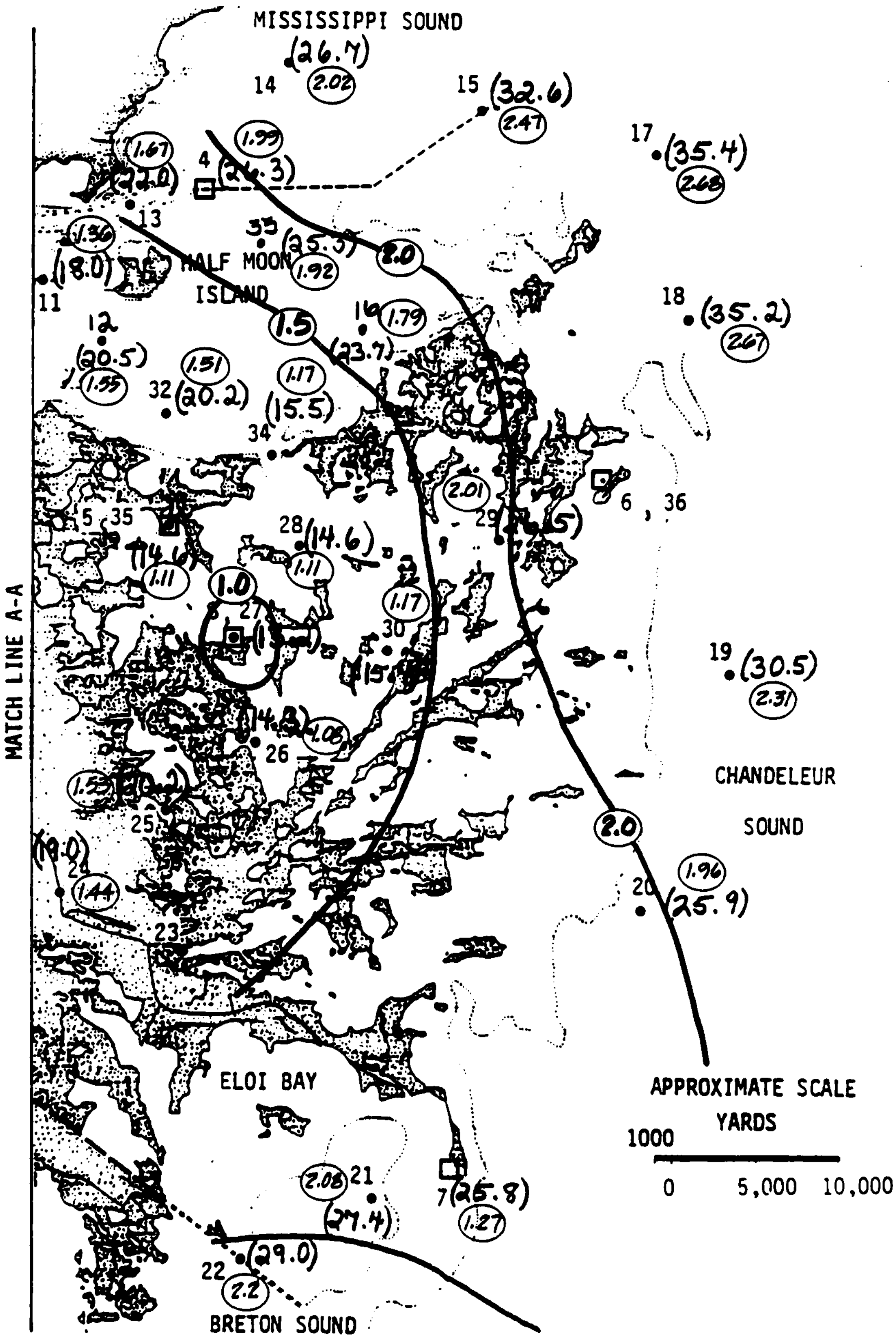

Figure A2. (Concluded)

The data listed in the facing table are also displayed in the figure following.

Table A3

Bay Boudreau Salinity and Temperature Data

Data Taken 15 October 1986

Station Number	Salinity, ppt Bottom	Salinity, ppt Mean*	Temperature, °C Bottom	Temperature, °C Mean*
1	11.5	11.5	23.8	23.8
2	-	11.1	-	23.8
3	14.7	14.6	22.8	22.8
4	16.2	16.1	23.1	23.1
5	16.2	16.2	23.8	23.4
6	16.5	16.4	23.5	23.2
7	14.8	14.6	24.6	24.3
8	16.6	16.1	24.4	24.0
9	16.5	15.9	22.8	22.7
10	17.7	17.7	24.1	23.3
11	17.9	17.7	22.3	22.2
12	20.5	19.5	22.5	22.2
13	19.5	18.6	22.8	22.4
14	24.6	24.2	21.9	21.7
15	26.1	25.7	22.2	22.4
16	27.1	26.7	22.7	22.5
17	30.3	29.3	22.7	22.6
18	30.4	29.6	22.9	22.6
19	30.6	29.9	22.4	21.2
20	30.0	29.6	22.3	22.1
21	24.4	24.3	23.1	23.0
22	28.8	25.5	23.1	23.3
23	23.7	23.7	22.7	22.7
24	21.7	21.7	22.8	22.6
25	-	23.5	-	20.6
26	23.2	23.1	20.8	20.7
27	21.6	21.5	21.3	21.2
28	24.1	24.0	21.7	21.6
29	28.5	28.2	21.4	21.2
30	23.4	23.4	20.9	20.8
31	18.0	17.9	23.6	23.4
32	21.8	21.6	22.2	22.1
33	23.0	22.9	22.8	22.7
34	25.8	25.6	21.6	21.5
35	19.2	19.3	21.5	21.3
TG1	10.4	10.4	23.6	23.5
TG2	15.8	15.7	22.7	22.6
TG3	24.3	21.3	24.2	24.9
TG4	20.0	19.0	22.9	22.8
TG5	19.2	19.3	21.5	21.3
TG6	-	28.7	-	21.4
TG7	24.7	24.6	23.2	23.2
TG8	21.6	21.5	21.3	21.2

* Average of bottom, middepth, and surface values.

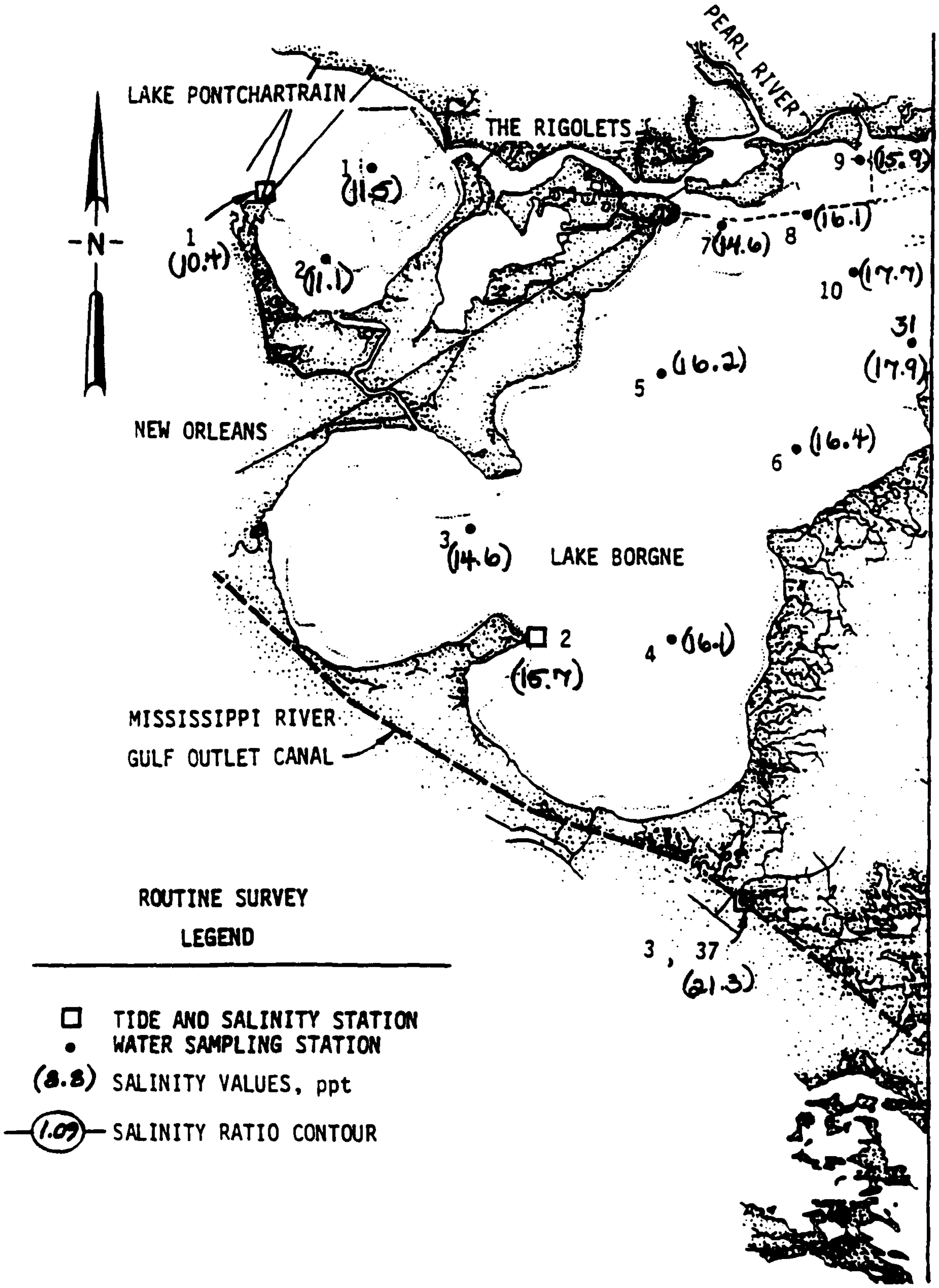

Figure A3. Bay Boudreau salinity data, 15 October 1986 (Continued)

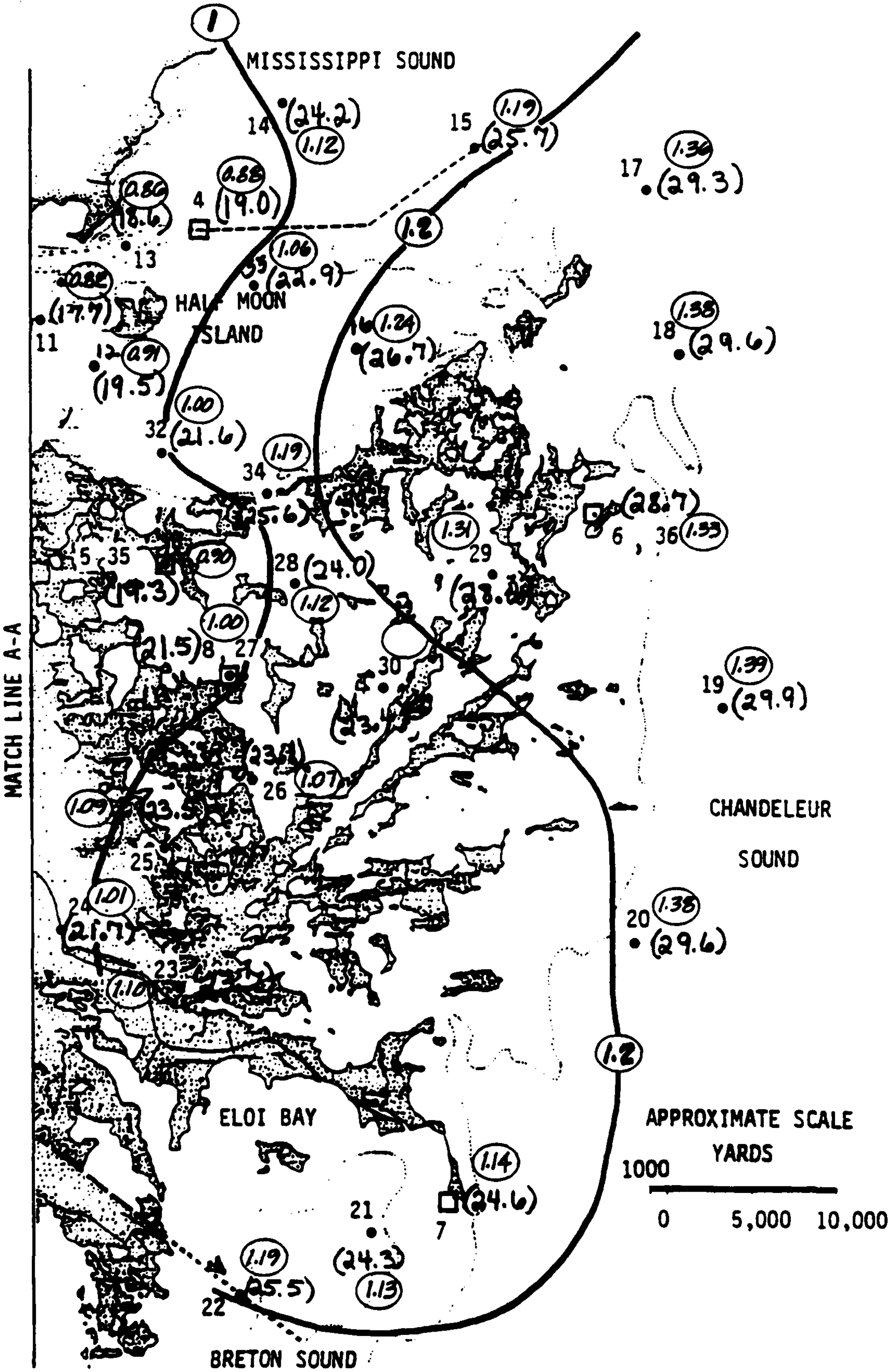

Figure A3. (Concluded)

The data listed in the facing table are also displayed in the figure following.

Table A4

Bay Boudreau Salinity and Temperature Data

Data Taken 18 and 19 November 1986

Station Number	Salinity, ppt Bottom	Salinity, ppt Mean*	Temperature, °C Bottom	Temperature, °C Mean*
1	8.9	9.0	18.4	18.3
2	9.6	9.7	18.8	18.7
3	14.1	13.8	18.0	18.0
4	16.2	15.9	18.0	18.0
5	13.8	13.6	17.8	17.9
6	15.6	15.6	18.3	18.3
7	10.4	9.9	18.3	18.4
8	10.2	10.1	18.3	18.3
9	12.0	10.1	18.5	18.8
10	13.3	13.3	18.0	18.1
11	14.7	14.2	18.1	18.1
12	15.3	15.2	18.0	18.0
13	15.4	14.7	18.1	18.2
14	19.2	19.0	18.2	18.2
15	22.2	22.1	18.0	18.1
16	18.9	18.8	18.5	18.5
17	27.2	26.2	17.9	18.0
18	27.9	27.5	18.3	18.5
19	30.0	30.1	19.0	19.0
20	29.9	28.7	18.5	18.4
21	25.4	25.6	18.2	18.2
22	30.3	27.6	18.0	18.0
23	22.6	22.9	20.1	19.9
24	20.4	20.5	20.4	20.4
25	-	21.4	-	20.7
26	21.4	21.3	20.6	20.7
27	20.3	20.3	19.3	19.3
28	19.3	19.3	19.3	19.4
29	26.3	26.8	18.9	19.0
30	23.4	23.4	19.8	19.8
31	15.0	15.0	18.2	18.2
32	15.9	15.9	18.3	18.3
33	19.3	18.6	18.0	18.1
34	18.0	16.7	19.0	19.1
35	19.0	18.6	19.5	19.5
TG1	8.7	8.7	19.0	19.0
TG2	15.2	15.2	19.3	19.6
TG3	19.7	19.6	20.3	20.3
TG4	13.7	13.6	18.3	18.2
TG5	19.0	18.6	19.5	19.5
TG6	-	28.2	-	20.1
TG7	18.3	18.2	28.4	27.8
TG8	20.3	20.3	19.3	19.3

* Average of bottom, middepth, and surface values.

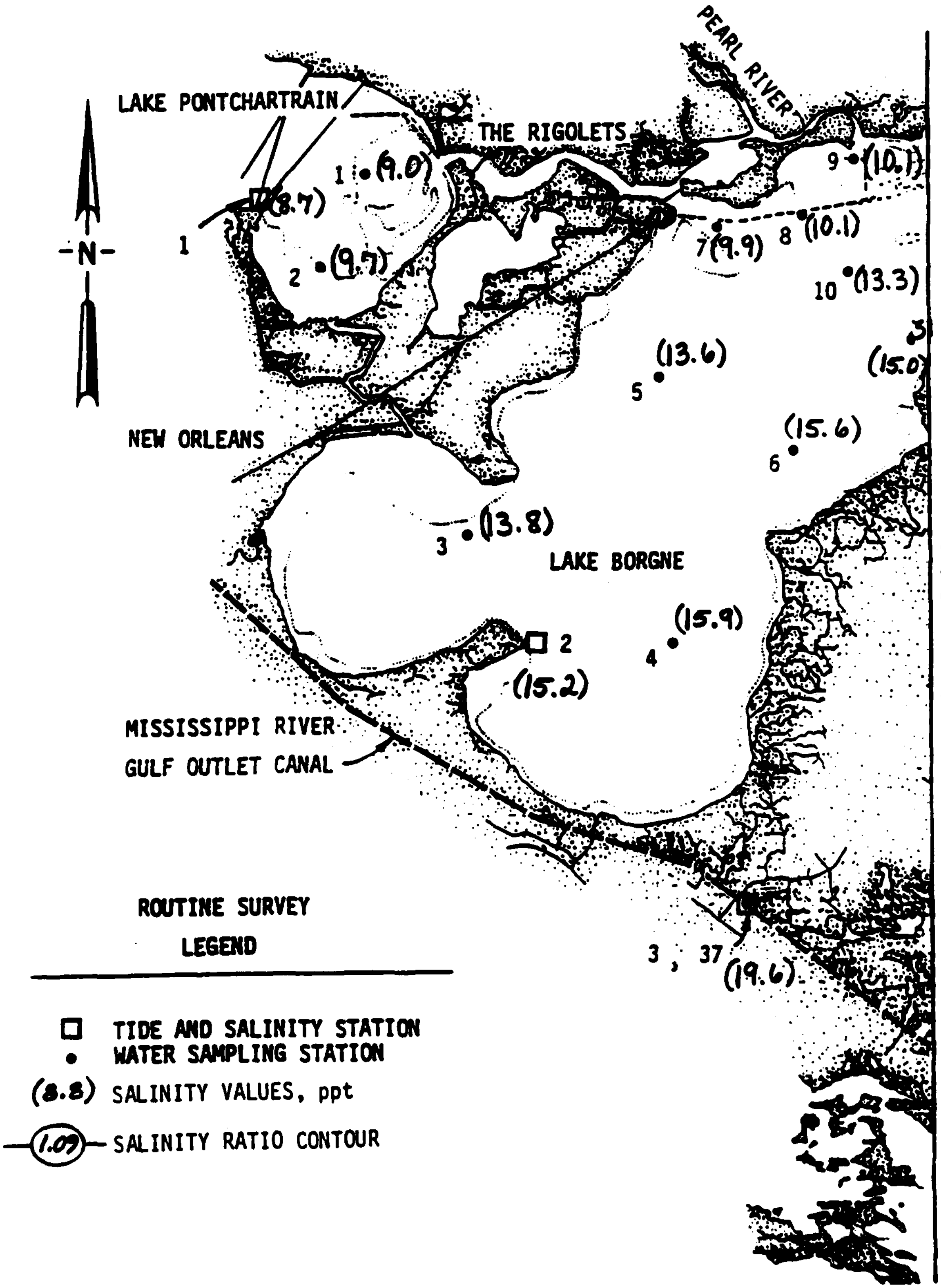

Figure A4. Bay Boudreau salinity data, 18 and 19 November 1986 (Continued)

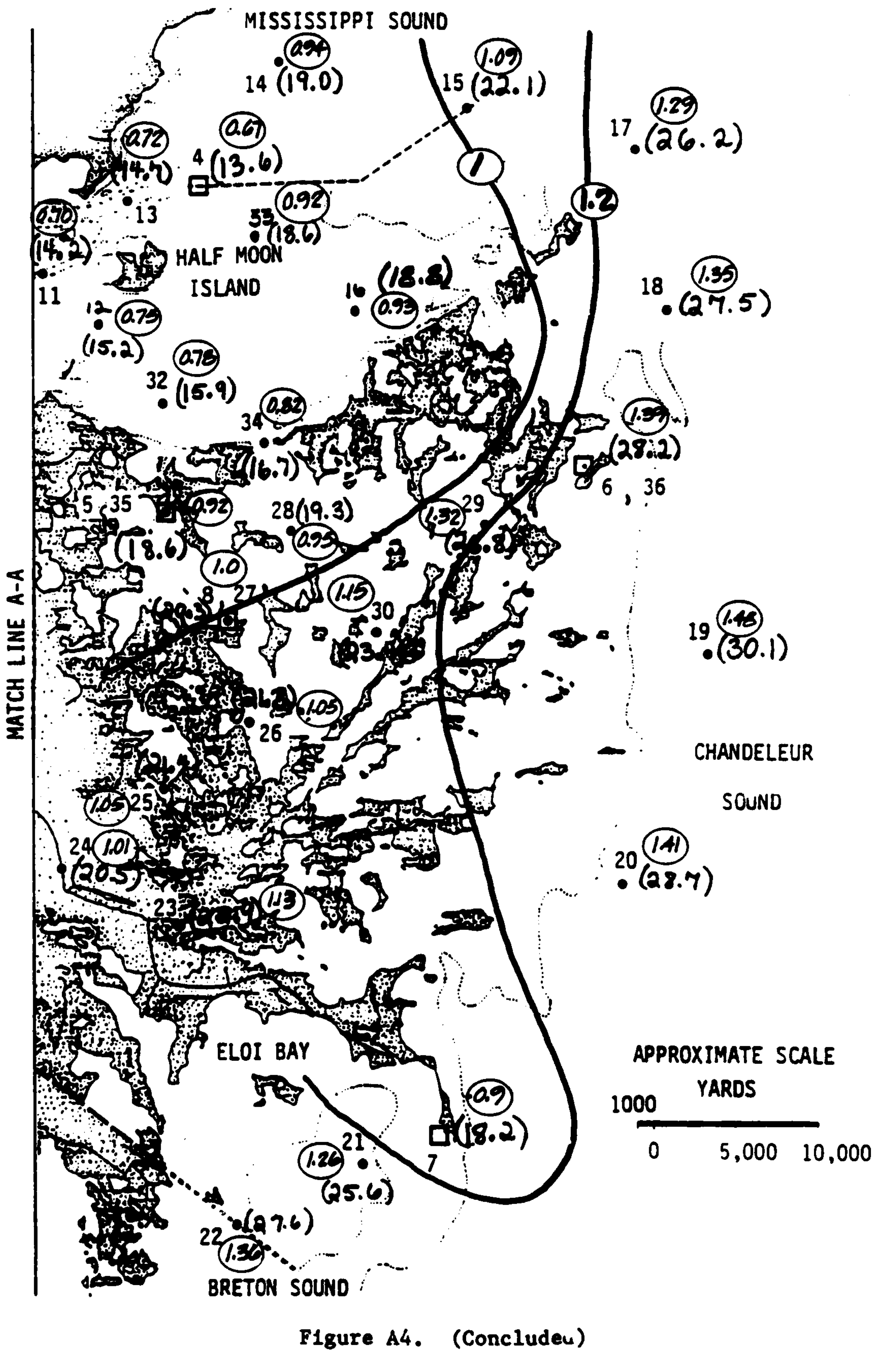

Figure A4. (Concluded)

The data listed in the facing table are also displayed in the figure following.

Table A5

Bay Boudreau Salinity and Temperature Data

Data Taken 13-15 December 1986

Station Number	Salinity, ppt		Temperature, °C	
	Bottom	Mean*	Bottom	Mean*
1	8.3	8.3	12.3	12.1
2	-	8.0	11.7	11.7
3	8.8	8.8	12.1	12.1
4	11.9	11.8	12.0	12.1
5	8.6	8.6	11.9	11.9
6	8.4	8.4	11.9	11.9
7	7.8	7.1	12.9	12.7
8	5.9	5.8	11.1	11.2
9	4.1	4.0	10.9	11.0
11	7.4	4.3	11.4	11.5
12	-	8.1	11.6	11.6
13	6.7	6.5	11.2	11.4
14	12.5	11.2	11.1	11.2
15	-	19.2	-	-
16	-	13.5	-	-
17	-	22.2	-	-
18	-	24.3	-	-
19	-	25.8	-	-
20	-	26.7	-	-
21	-	15.3	-	-
22	-	16.2	-	-
23	-	15.2	-	-
24	-	16.6	-	-
25	-	13.4	-	-
26	-	12.5	-	-
27	-	12.0	-	11.4
28	-	11.3	-	-
29	-	21.8	-	-
30	-	13.7	-	-
31	8.9	8.8	11.6	11.6
32	9.9	9.7	11.6	11.6
33	9.8	8.9	11.5	11.6
34	-	12.4	-	-
35	9.9	9.9	11.5	11.5
TG1	7.8	7.8	12.3	12.2
TG2	-	11.6	-	-
TG3	-	12.3	-	-
TG4	6.7	6.7	11.4	11.5
TG5	9.9	9.9	11.5	11.5
TG6	-	22.0	-	-
TG7	-	17.8	-	-
TG8	-	12.0	-	11.4

* Average of bottom, middepth, and surface values.

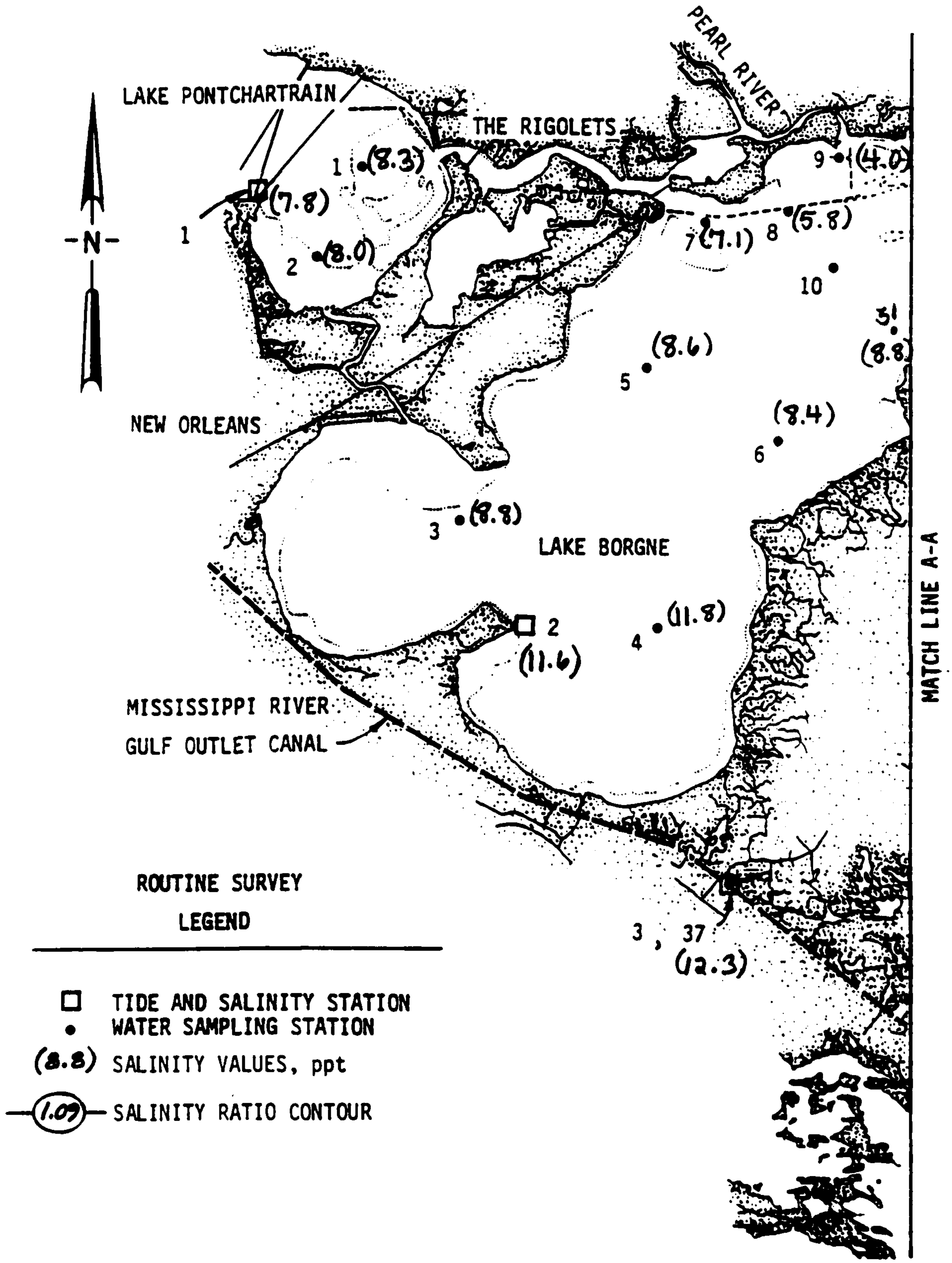

Figure A5. Bay Boudreau salinity data, 13-15 December 1986 (Continued)

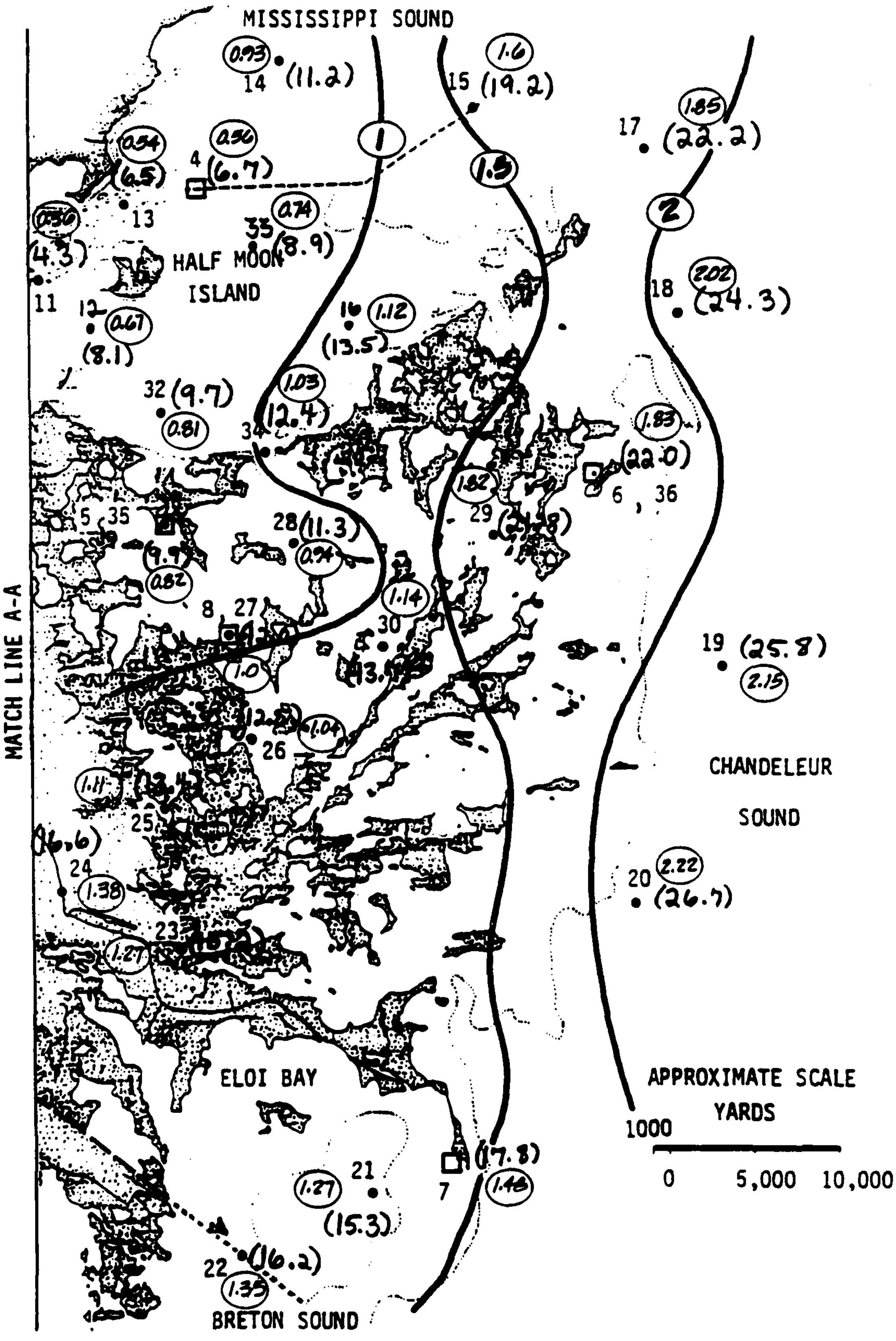

Figure A5. (Concluded)

The data listed in the facing table are also displayed in the figure following.

Table A6

Bay Boudreau Salinity and Temperature Data

Data Taken 26 and 28 May 1987

Station Number	Salinity, ppt		Temperature, °C	
	Bottom	Mean*	Bottom	Mean*
1	6.1	6.1	27.3	27.3
2	6.1	6.2	27.6	27.5
3	7.3	7.3	27.6	27.6
4	7.1	7.1	27.3	27.3
6	9.3	9.2	27.3	27.3
8	10.4	10.3	27.1	27.2
9	9.9	9.9	26.5	26.7
13	14.5	14.3	26.9	26.9
14	18.0	17.9	26.7	26.7
15	20.1	20.1	26.5	26.5
17	23.0	22.9	27.2	27.3
18	23.9	23.9	27.3	27.3
26	23.1	23.1	26.8	26.8
29	24.4	24.5	27.0	26.9
30	22.0	22.0	26.6	26.6
31	11.4	11.4	27.2	27.3
35	14.8	13.9	26.2	26.7
TG1	6.0	6.0	28.0	28.0
TG2	8.6	8.6	27.9	27.9
TG3	19.9	19.2	26.9	27.3
TG4	14.8	14.8	27.6	27.4
TG6	23.8	23.9	26.7	26.7
TG8	20.2	20.2	26.8	26.8

* Average of bottom, middepth, and surface values.

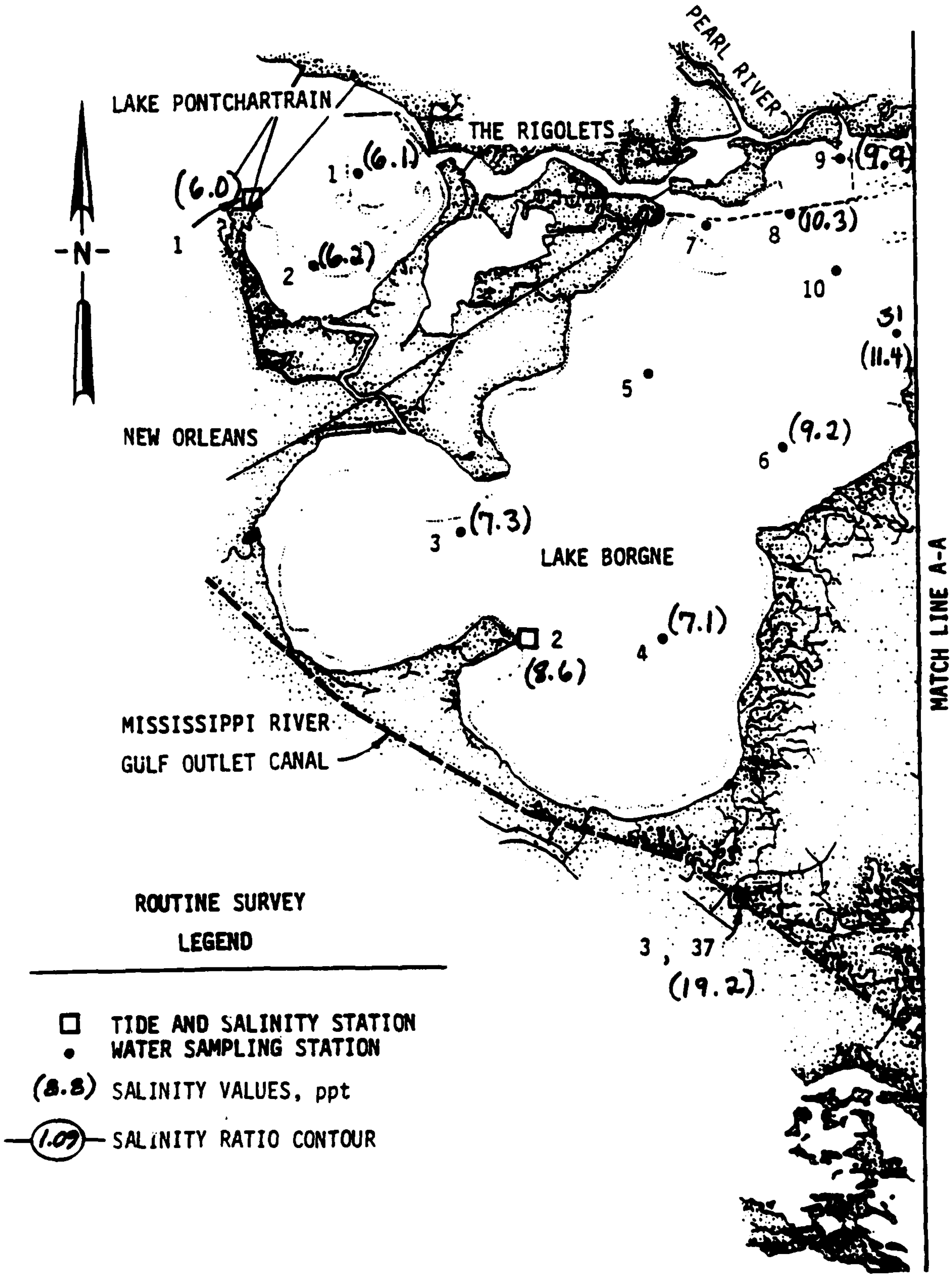

Figure A6. Bay Boudreau salinity data, 26 and 28 May 1987 (Continued)

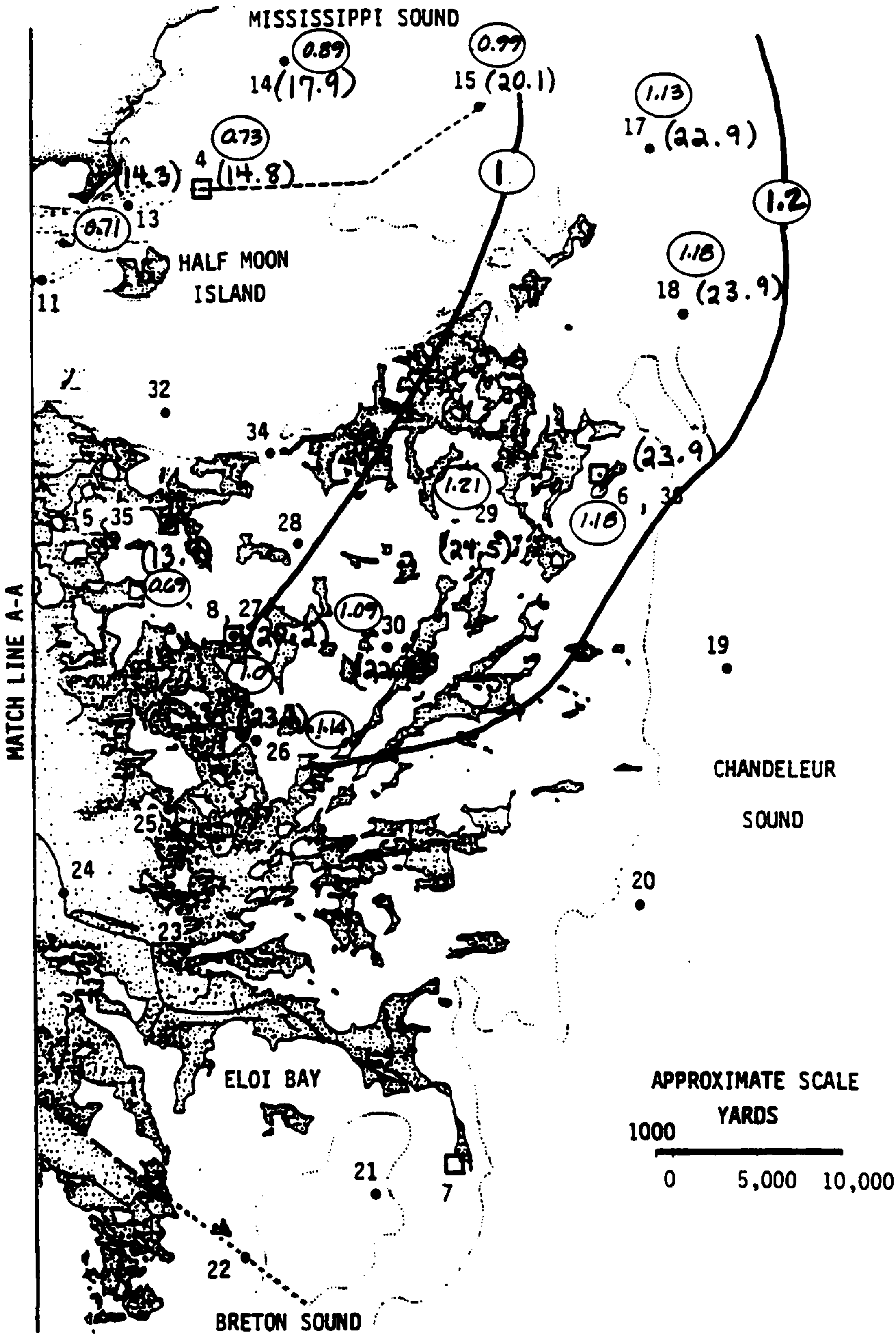

Figure A6. (Concluded)

The data listed in the facing table are also displayed in the figure following.

Table A7

Bay Boudreau Salinity and Temperature Data

Data Taken 12 and 13 September 1987

Station Number	Salinity, ppt		Temperature, °C	
	Bottom	Mean*	Bottom	Mean*
1	4.1	4.1	28.9	28.9
2	-	5.1	-	29.6
3	9.3	9.3	28.0	28.0
4	9.6	9.5	28.2	28.2
5	8.0	7.9	28.2	28.4
6	9.1	9.1	28.4	28.4
7	8.2	7.9	28.6	28.3
8	10.7	10.5	28.3	28.5
9	10.3	9.6	28.2	28.2
10	8.5	8.0	28.0	28.2
11	10.1	10.1	28.2	28.3
12	12.6	10.7	27.9	28.1
13	14.1	13.5	28.8	28.9
16	18.9	15.2	28.8	28.5
19	25.4	25.4	28.2	28.2
20	26.1	26.1	28.1	28.2
21	-	24.2	-	27.8
22	28.4	26.8	28.7	28.5
23	-	20.4	-	27.9
24	19.4	19.3	28.5	28.5
26	-	16.3	-	27.3
28	-	14.2	-	27.2
29	-	18.9	-	27.4
30	-	17.8	-	27.2
34	14.3	13.5	27.4	27.5
35	9.0	8.9	27.4	27.6
TG1	4.2	4.3	28.8	28.8
TG2	9.3	9.2	28.5	28.7
TG3	26.0	23.2	29.3	28.3
TG4	14.7	14.6	28.2	28.6
TG6	-	19.6	-	28.9
TG7	25.8	25.8	27.9	27.9
TG8	-	11.9	-	28.3

* Average of bottom, middepth, and surface values.

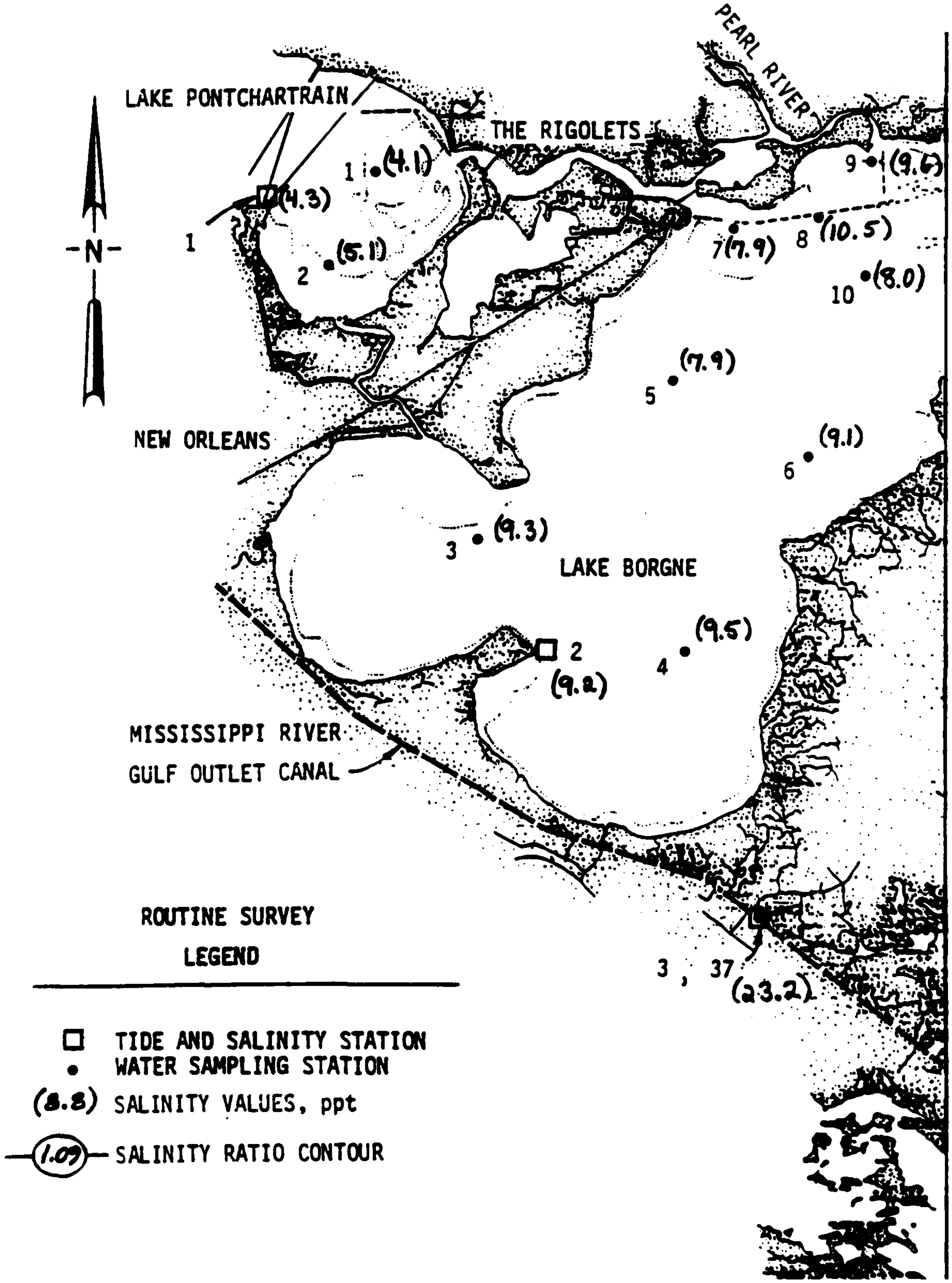

Figure A7. Bay Boudreau salinity data, 12 and 13 September 1987 (Continued)

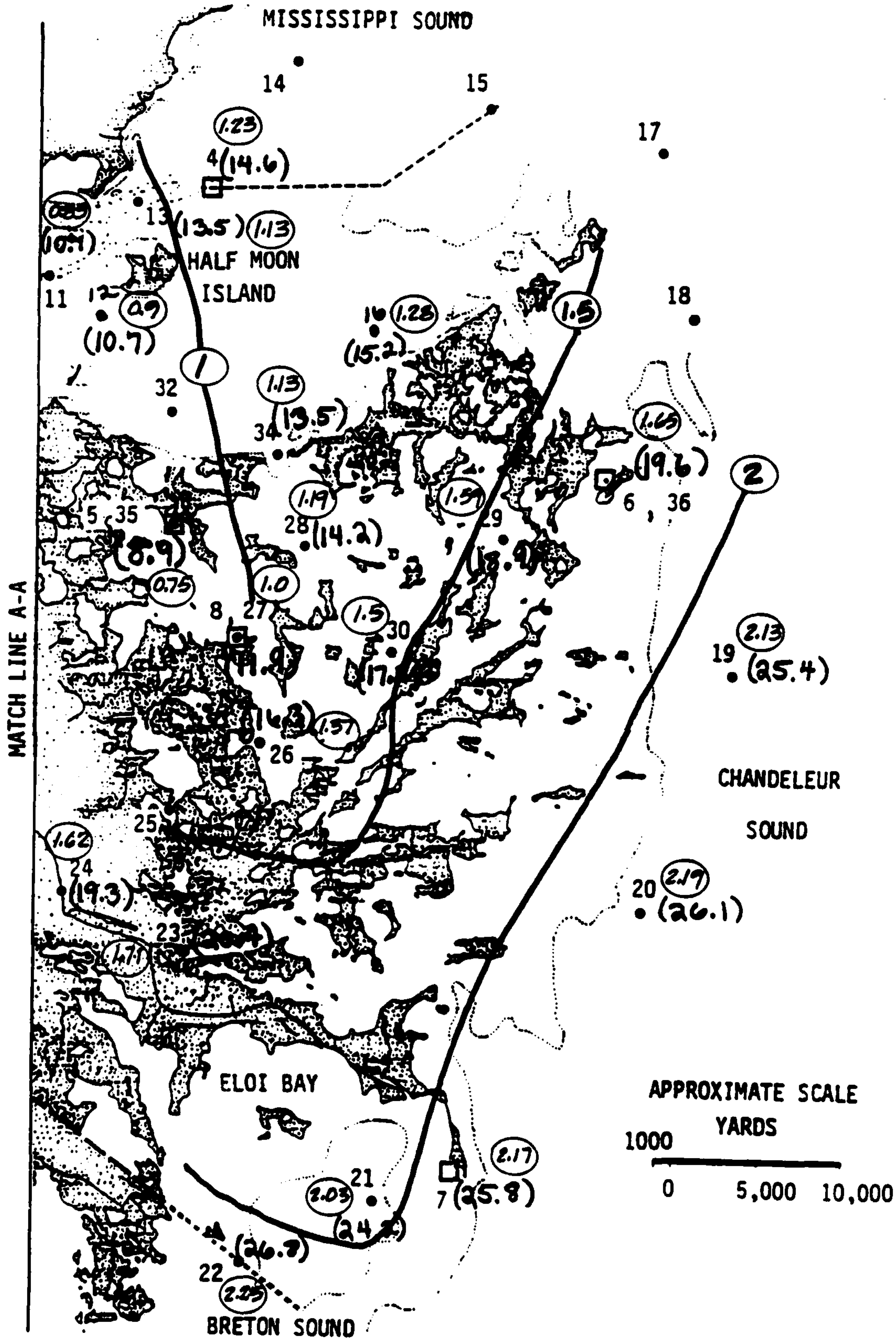

Figure A7. (Concluded)

APPENDIX B: CROSS-SPECTRAL ANALYSES OF BAY BOUDREAU SALINITIES AND RELATED PROCESSES

Introduction

1. Salinities in the Bay Boudreau area are influenced by a number of physical processes. Defining the relationships between salinity and the related processes by regression benefits from or even requires some a priori knowledge of the form of the relationship, e.g., the time lag between an event such as freshwater runoff and resulting salinity changes. One way of defining these relationships is to employ cross-spectral analyses.

Objective

2. The purpose of this task was to define the relationships between salinity and such physical process forcing functions as riverflow in terms of amplitude and phase responses.

Spectral analysis

3. Spectral analysis transforms time series data such as time-histories of salinity into the frequency domain by means of Fourier series. For example, hundreds of data points making up a sine wave in time are represented in the frequency domain by three parameters--an amplitude, a frequency, and a phase. The Fourier analysis used in spectral analysis enables the same data set to be viewed in either the time or frequency domains, but the frequency domain has some advantages.

4. It should be noted that spectral analysis uses terms suitable for periodic functions, but the analyses are also applicable to aperiodic time series data.

5. In the frequency domain, the relationship between two related processes can be expressed as a response amplitude (e.g., ratio of parts per thousand salinity change to cubic feet per second flow change) and a phase lag (e.g., days between freshwater pulse maximum and salinity minimum) at each frequency examined. The response is expressed as a response function amplitude (RFA).

6. The degree of relationship between two time series is expressed as a coherency in spectral analysis. The coherency squared (COH2) can be considered loosely equivalent to the correlation coefficient in regression analyses. A COH2 value of 0 indicates no linear correlation between the two series. A

value of 1 indicates perfect linear correlation.

7. The computations consist of multiplying two time series together when they are matched in time, then shifted (lagged) by one data point time interval with respect to each other and multiplied again, then shifted and multiplied repeatedly to some maximum number of lags. A higher number of maximum lags increases the resolution of the results but decreases the quality of the answer since one data point is lost each time the series are shifted. In general, the maximum lag should be no longer than 10 to 15 percent of the total length of the data record.

8. Fourier analysis as used here assumes that an infinitely long data record is available. To account for finite record lengths, the mathematics rely on an assumption that a window has been used that multiplies all values outside the window (the time before the data record starts and the time after it ends) by zero. Several different types of windows are employed, depending on the application. In this work, boxcar and Tukey-Hanning windows were used, but only the Tukey-Hanning results are presented. The Tukey-Hanning window is tapered toward the beginning and end of the data record, so that abrupt discontinuities are diminished.

9. Spectral analysis is described more fully by Donnell and McAnally (1985).* For details of the methods employed here, see that report.

Computations Performed

Data used

10. Cross-spectral computations were performed between salinity in Bay Boudreau and each of the following:

- a. Freshwater flows from the Pearl River.
- b. Flows from Lake Pontchartrain tributaries.
- c. Water levels at tide gages 5 and 8.
- d. Precipitation.
- e. Temperature.
- f. Wind.

Precipitation, temperature, and wind were obtained from the National Oceanic

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* References cited in this Appendix are included in the References at the end of the main text.

and Atmospheric Administration (NOAA) records at the New Orleans Airport (NOAA 1986c, 1987b). River flows were from the US Geological Survey (USGS) records. Water levels and salinities were those measured during the 1986-1987 US Army Engineer Waterways Experiment Station (WES) data collection.

11. Data used were daily averages with a time interval of 1 day in all cases. Water levels and salinities were 24-hour averages (midnight to midnight).

12. Winds were analyzed in three ways--wind speed alone, north-south components of wind, and east-west components of wind.

13. Spectral analysis requires continuous time series data. Continuous salinity and water level records were constructed by combining data from WES stations 5 and 8 as described in the following paragraph. The other data series were essentially continuous as received.

14. Station 5 and 8 salinities were used for the period 25 June 1986-8 December 1987. The records had a number of gaps in one or both stations. To fill these gaps, the available data were averaged to produce a single record. Where both station salinities were missing, one of two representative values was used--the overall average of 10.6 ppt or zero. Examination of the spectral results indicated that using 10.6 ppt for the missing values was most appropriate, and only those are presented here.

15. A similar process was used to construct a complete data record of daily average water levels at stations 5 and 8.

Calculation methods

16. The WES computer program SPECTRA3 was used to perform the spectral calculations. Calculations with maximum lags of 30, 46, 50, 91, and 183 days were performed. The 10-15 percent maximum lag rule (see paragraph 7 of this appendix) would limit the maximum lag to 53-79 days, but the larger maximum lags were necessary to obtain estimates of response at the seasonal and annual periods. Window closing (Donnell and McAnally 1985) was performed to optimize the results. Nevertheless, results for the 183 lags (period of 366 days) are suspect and should be used only with great care.

17. One artifact of too many lags is unrealistically high COH2 values caused by too few degrees of freedom. Within a given set of calculations with the same maximum lag, these high values can be considered useful by their relative magnitude; however, they should not be compared with COH2 values from calculations made with different maximum lags.

18. Numerous sets of calculations were made using the basic data sets described in paragraph 10 of this appendix. The results were examined in their raw form to identify which forcing function processes had a significant effect on salinities at what frequencies. Only those results of significance to the desired goals are presented here, but the entire results are on file. Significant results were those displaying COH2 values and RFA's that were high with respect to other results in the same set of calculations.

Results

19. Selected results are presented in Tables B1-B3.

20. Table B1 summarizes the spectral results at important frequencies where correlation was observed. It includes the auto spectral density (ASD) of the several forcing functions, the RFA of the salinity to the forcing function, the COH2, and phase shift between forcing function and salinity, all at four frequencies--periods that are annual (366 days), seasonal (92 days), monthly (30 days), and a short period (3 to 9 days). The latter was selected from the computed spectra at the frequencies where coherence was greatest within the 3- to 9-day range. Each result was selected from a run with the smallest number of maximum lags that resolved that frequency. Salinity at stations 5 and 8 demonstrated an annual spectral cycle variability of 8 to 10 ppt and a seasonal cycle variability of 4 to 6 ppt. The total variability (minimum to maximum measured values) was about 16 ppt.

21. Table B1 also includes two secondary measures of relationship between the forcing functions and salinity--normalized RFA (NRFA) and coherent normalized RFA (CNRFA)--that attempt to bring all the various forcing functions to the same basis. NRFA is the RFA multiplied by the square root of the forcing function ASD and the frequency bandwidth. Thus NRFA values are in salinity units of parts per thousand (amplitude of the salinity function), which are directly comparable between forcing functions and enable ranking their relative impact. CNRFA is the product of NRFA and COH2 so that relative impact is weighted by the degree of correlation exhibited.

22. Table B1 presents the summary of spectral results in frequency groups. Within each group, the forcing functions are sorted by normalized RFA. Tables B2 and B3 present the same information sorted two different ways:

Table B2 sorts on the basis of NRFA only and Table B3 sorts on the basis of CNRFA.

23. Table B1 shows how the various forcing functions rank in NRFA at the three significant frequencies. The annual fluctuations cause a salinity amplitude response of about 2-3 ppt, whereas the seasonal fluctuations cause a response of about 1 to 2 ppt for each function. Of the short-term changes, only the Pearl River has a definite impact (at frequency 0.26, period 3.8 days) and the resulting salinity change is less than 1 ppt. At this frequency, precipitation rises from near last place to show some possible significance. These short-term effects probably correspond to single storm events.

24. Frequencies were selected for inclusion in Tables B1-B3 based on a high coherency and known periodicities in the forcing functions, with the exception of the 30-day period. The 30-day period is presented because it was the averaging period used in the regression analyses. While 30 days is a convenient averaging period, Tables B1-B3 shows what is intuitively obvious--it is not a natural period of any of the processes of interest. It exhibits minimal coherence for all forcing functions. A lack of periodicity and coherence at 30 days does not mean that 30-day averaging is an unacceptable filter, but it does mean that it will introduce noise in the record that will complicate regression and give lower correlation coefficients.

25. Table B3 can be roughly translated as an order of significance. If regression functions are chosen from this table, a cutoff would seem logical at a CNRFA of about 0.25.

Conclusions

26. The data sets are too short for reliably defining true salinity responses except at periods of less than about 3 months.

27. Seasonal variation in salinity at stations 5 and 8 ranged from 4 to 6 ppt during the 1986-1987 data period.

28. Using a calendar monthly average analysis will introduce noise that complicates interpretation.

29. None of the six forcing functions can be ignored without introducing an error that is large with respect to the intended salt response, although some can be ignored at selected frequencies. A model intended for

operation of the structure should include at least the forcing functions in the top half of Table B3.

30. The results show plainly that the salinity is relatively insensitive to short bursts of flow from Lake Pontchartrain. Only at seasonal periods does it begin to assume any importance compared to the other effects. This means that flows through the Bonnet Carre structure will have to be programmed well in advance of the actual need.

Table B1

Bay Boudreau Spectral Analysis

Forcing Function Name	ASD	RFA	NRFA ppt	COH2	CNRFA	Phase days	Frequency CPD
Period = 366 Days, Frequency = 0.0027 CPD							
Lake Pontchartrain	265,000	0.09	2.41	0.88	2.04	255	
Water level	9.23	15	2.37	0.86	0.57	171	
Temperature	2.25	29.7	2.31	0.82	0.99	265	
Pearl River	1,940,000	0.03	2.17	0.90	2.12	232	
E-W wind	175	2.72	1.87	0.53	1.95	149	
Precipitation	0.8	33	1.53	0.37	1.90	228	
Period = 92 Days, Frequency = 0.0109 CPD							
Water level	5.35	7.3	1.76	0.35	0.62	43	
Pearl River	678,000	0.02	1.72	0.35	0.60	51	
Lake Pontchartrain	103,200	0.05	1.68	0.31	0.52	50	
E-W wind	188	0.94	1.35	0.20	0.27	43	
Precipitation	0.54	11	0.84	0.08	0.07	64	
Temperature	0.60	10	0.81	0.07	0.06	64	
Period = 30 Days, Frequency = 0.0333 CPD							
Temperature	0.012	34	0.68	0.20	0.14	8	
Pearl River	69,200	0.01	0.48	0.12	0.06	17	
E-W wind	66	0.32	0.47	0.08	0.04	16	
Lake Pontchartrain	40,100	0.01	0.37	0.04	0.01	18	
Water level	1.07	1.93	0.36	0.05	0.02	10	
Precipitation	0.36	2.6	0.28	0.03	0.01	8	
Period = 3 to 9 Days, Frequency = 0.333 to 0.110 CPD							
Pearl River	26.7	0.36	0.95	0.75	0.71	2	.26
Precipitation	0.25	3.4	0.78	0.47	0.37	2	.21
E-W wind	38.5	0.28	0.74	0.39	0.29	4	.18
Lake Pontchartrain	2,051	0.03	0.58	0.20	0.12	4	.18
Water level	0.351	2.07	0.55	0.23	0.13	2	.20
Temperature	0.0058	16	0.47	0.30	0.14	2	.15

Note: $\mathrm{NRFA} = \mathrm{RFA}\sqrt{\mathrm{ASD}\left(\frac{1}{\text{estimate bandwidth}}\right)}$

CNRFA = NRFA * COH2

Phase is from maximum of forcing function to minimum of salinity

CPD = Cycles per day

Table B2

Bay Boudreau Spectral Analysis

Sorted by NRFA*

Forcing Function Name	ASD	RFA	NRFA ppt	COH2	CNRFA	Frequency CPD
Lake Pontchartrain	265,000	.09	2.41	.88	2.04	.0027
Water level	9.23	15	2.37	.86	.57	.0027
Temperature	2.25	29.7	2.31	.82	.99	.0027
Pearl River	1,940,000	.03	2.17	.90	2.12	.0027
E-W wind	175	2.72	1.87	.53	1.95	.0027
Water level	5.35	7.3	1.76	.35	.62	.0109
Pearl River	678,000	.02	1.72	.35	.60	.0109
Lake Pontchartrain	103,200	.05	1.68	.31	.52	.0109
Precipitation	.80	33	1.53	.37	1.90	.0027
E-W wind	188	.94	1.35	.20	.27	.0109
Pearl River	26.7	.36	.95	.75	.71	.26
Precipitation	.54	11	.84	.08	.07	.0109
Temperature	.60	10	.81	.07	.06	.0109
Precipitation	.25	3.4	.78	.47	.37	.21
E-W wind	38.5	.28	.74	.39	.29	.18
Temperature	.012	34	.68	.20	.14	.0333
Lake Pontchartrain	2,051	.03	.58	.20	.12	.18
Water level	.351	2.07	.55	.23	.13	.2
Pearl River	69,200	.01	.48	.12	.06	.0333
E-W wind	66	.37	.47	.08	.04	.0333
Temperature	.0058	16	.47	.30	.14	.15
Lake Pontchartrain	40,100	.01	.37	.04	.01	.0333
Water level	1.07	1.93	.36	.05	.02	.0333
Precipitation	.36	2.6	.28	.03	.01	.0333

* Data are arranged by descending value of NRFA.

Table B3

Bay Boudreau Spectral Analysis

Sorted by CNRFA*

Forcing Function Name	ASD	RFA	NRFA ppt	COH2	CNRFA	Frequency CPD
Pearl River	1,940,000	.03	2.17	.90	2.12	.0027
Lake Pontchartrain	265,000	.09	2.41	.88	2.04	.0027
E-W wind	175	2.72	1.87	.531	.95	.0027
Precipitation	.80	33	1.53	.37	1.90	.0027
Temperature	2.25	29.7	2.31	.82	.99	.0027
Pearl River	26.7	.36	.95	.75	.71	.26
Water level	5.35	7.3	1.76	.35	.62	.0109
Pearl River	678,000	.02	1.72	.35	.60	.0109
Water level	9.23	15	2.37	.86	.57	.0027
Lake Pontchartrain	103,200	.05	1.68	.31	.52	.0109
Precipitation	.25	3.4	.78	.47	.37	.21
E-W wind	38.5	.28	.74	.39	.29	.18
E-W wind	188	.94	1.35	.20	.27	.0109
Temperature	.0058	16	.47	.30	.14	.15
Temperature	.012	34	.68	.20	.14	.0333
Water level	.351	2.07	.55	.23	.13	.2
Lake Pontchartrain	2,051	.03	.58	.20	.12	.18
Precipitation	.54	11	.84	.08	.07	.0109
Pearl River	69,200	.01	.48	.12	.06	.0333
Temperature	.60	10	.81	.07	.06	.0109
E-W wind	66	.32	.47	.08	.04	.0333
Water level	1.07	1.93	.36	.05	.02	.0333
Lake Pontchartrain	40,100	.01	.37	.04	.01	.0333
Precipitation	.36	2.6	.28	.03	.01	.0333

* Data are arranged by descending value of CNRFA.

APPENDIX C: LMN AND WES REGRESSION MODELS WITH VARIABLE TARGET FACTORS

1. During earlier work, US Army Engineer District, New Orleans, and US Army Engineer Waterways Experiment Station (WES) regression equations were rearranged and solved for required Lake Pontchartrain flows to achieve target salinities during a yearly schedule. The target salinity for June was adjusted to 10.3 from 12.5 for the LMN model predictions. Monthly flow levels corresponding to the 50 percent frequency of occurrence were used. The difference between the required flow and the 50 percent Lake Pontchartrain flow was the required diversion flow.

2. Target salinities defined in paragraph 3 of the main text are the desired average salinities for the Bay Boudreau area of the Biloxi marshes. Regressions were performed not on areal average salinities, but on point salinities at stations 5 and 8 (1986-1987) and Treasure Pass (1971-1978). In order to use the regression results to generate the areal targets, two approaches were possible: (a) the point salinities could be adjusted so that equivalent areal salinities were regressed, or (b) the target salinities could be modified so as to make them point targets. The latter approach was selected.

3. Stations 5 and 8 were found to be fresher than average for Bay Boudreau. An adjustment in the target salinities by a multiplier factor of 0.77 was made to ensure that the target was met on average in Bay Boudreau (Tables 11-14 of the main text). Average salinities over the Bay Boudreau area were calculated by averaging values from stations 23, 25, 27, 28, 29, 30, 34, 35, and 36. The average ratio of salinities at stations 5 and 8 to the Bay Boudreau average was 0.77 with a standard deviation of 0.09. The average ratio of salinities at Bay Boudreau to station 23 near Treasure Pass was 1.10 with a standard deviation of 0.12. Tables C1-C10 show the LMN model that was replicated (Table 5, main text) and the various WES models that were compared to the LMN model (Tables 6-14, main text).

4. These target factors are subject to seasonal and annual variation; so the calculated factors should be considered only approximate. A range of target factor values (0.25 to 0.77) was tested for the station 5 and 8 regressions to examine the resulting change in required diversion flows. Target factors are included in Tables C1-C10. These factors were multiplied times

the target salinities in solving for a required diversion flow.

5. These analyses lead to the conclusion that spatial variability in observed salinities and regression uncertainty caused by finite record length and nonmodeled factors can be accounted for by using the higher maximum needed flows (i.e., 30,000 cfs) as a design capacity figure for the diversion structure.

Table C1

Computed Diversion Flows Using LMN Model and LMN Coefficients and Salinity Targets*

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity for Stations 5 and 8 ppt
Jan	16.0	297,662	131,967	0	0	14.1
Feb	14.0	505,680	147,868	38,727	1,291	11.8
Mar	9.5	592,720	169,911	337,753	11,258	9.5
Apr	8.0	465,300	127,950	888,791	29,626	8.0
May	8.0	312,790	90,328	527,895	17,597	8.0
Jun	12.5	125,340	51,273	436,214	14,540	10.3
Jul	13.0	109,182	53,150	99,761	3,325	13.0
Aug	16.0	86,552	46,544	81,598	2,720	16.0
Sep	17.0	71,640	41,607	60,654	2,022	17.0
Oct	17.0	63,457	36,809	165,703	5,523	17.0
Nov	16.0	79,530	38,562	93,881	3,129	16.0
Dec	16.0	165,509	95,936	0	0	16.0

* LMN model and LMN coefficients (step backwards).

Table C2

Computed Diversion Flows Using LMN Model and LMN Coefficients with Salinity Targets Adjusted by a Factor of 1.1*

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity for Stations 5 and 8 ppt
Jan	16.0	297,662	131,967	0	0	14.1
Feb	14.0	505,680	147,868	0	0	12.9
Mar	9.5	592,720	169,911	21,2038	7,068	9.9
Apr	8.0	465,300	127,950	520,777	17,359	8.8
May	8.0	312,790	90,328	580,446	19,348	8.8
Jun	12.5	125,340	51,273	357,200	11,907	10.3
Jul	13.0	109,182	53,150	15,321	511	14.3
Aug	16.0	86,552	46,544	31,311	1,044	17.6
Sep	17.0	71,640	41,607	0	0	18.7
Oct	17.0	63,457	36,809	140618	4687	18.3
Nov	16.0	79,530	38,562	0	0	17.6
Dec	16.0	165,509	95,936	0	0	17.1

* LMN model and LMN coefficients (step backwards).

Table C3

Computed Diversion Flows Using Equation M2* and Target Factor 0.77

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity for Stations 5 and 8 ppt
Jan	16.0	297,662	131,967	0	0	11.7
Feb	14.0	505,680	147,868	116,498	3,883	10.0
Mar	9.5	592,720	169,911	133,901	4,463	7.3
Apr	8.0	465,300	127,950	152,596	5,087	6.2
May	8.0	312,790	90,328	0	0	6.2
Jun	12.5	125,340	51,273	30,355	1,012	9.0
Jul	13.0	109,182	53,150	0	0	10.0
Aug	16.0	86,552	46,544	0	0	11.3
Sep	17.0	71,640	41,607	0	0	12.0
Oct	17.0	63,457	36,809	82,067	2,736	12.5
Nov	16.0	79,530	38,562	65,978	2,199	12.3
Dec	16.0	165,509	95,936	0	0	12.3

* WES model SALN = B1 * ln (LP1 + RF1) + B2 * ln (PR2) + Int; (step backwards) B1: -3.5130; B2: -1.6227; Int: 72.6453

Table C4

Computed Diversion Flows Using Equation M5* and Target Factor 0.77

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity for Stations 5 and 8 ppt
Jan	16.0	297,662	131,967	0	0	11.2
Feb	14.0	505,680	147,868	62,942	2,098	9.5
Mar	9.5	592,720	169,911	79,752	2,658	7.3
Apr	8.0	465,300	127,950	108,960	3,632	6.2
May	8.0	312,790	90,328	3,659	122	6.2
Jun	12.5	125,340	51,273	45,019	1,501	9.6
Jul	13.0	109,182	53,150	6,825	228	10.0
Aug	16.0	86,552	46,544	3,907	130	12.3
Sep	17.0	71,640	41,607	11,436	381	13.1
Oct	17.0	63,457	36,809	42,868	1,429	13.1
Nov	16.0	79,530	38,562	37,262	1,242	12.3
Dec	16.0	165,509	95,936	0	0	12.3

* WES model SALN = B1 * ln (LP1) + B2 * ln (PR2 + RF1) + Int; (step backwards) Sta. 5 & 8; B1: -3.4615; B2: -1.3683; Int: 67.3517 Sta. 4; B1: -8.6156; B2: 3.5190; Int: 66.0826.

Table C5

Computed Diversion Flows Using Equation M9* and Target Factor 0.77

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity for Stations 5 and 8 ppt
Jan	16.0	297,662	131,967	0	0	10.4
Feb	14.0	505,680	147,868	0.	0	9.0
Mar	9.5	592,720	169,911	21,351	712	8.5
Apr	8.0	465,300	127,950	120,068	4,002	7.3
May	8.0	312,790	90,328	157,690	5,256	6.2
Jun	12.5	125,340	51,273	62,470	2,082	6.2
Jul	13.0	109,182	53,150	51,155	1,705	9.6
Aug	16.0	86,552	46,544	15,486	516	10.0
Sep	17.0	71,640	41,607	10,556	352	12.3
Oct	17.0	63,457	36,809	15,354	512	13.1
Nov	16.0	79,530	38,562	23,468	782	13.1
Dec	16.0	165,509	95,936	0	0	12.3

* WES model SALN = B1 * ln (LP1) + Int; (step forwards) B1: -4.4448; Int: 61.3654.

Table C6

Computed Diversion Flows Using Equation M8* and Target Factor 0.77

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity for Stations 5 and 8 ppt
Jan	16.0	297,662	131,967	0	0	11.2
Feb	14.0	505,680	147,868	50,408	1,680	9.4
Mar	9.5	592,720	169,911	67,731	2,258	7.3
Apr	8.0	465,300	127,950	100,831	3,361	6.2
May	8.0	312,790	90,328	5,926	198	6.2
Jun	12.5	125,340	51,273	44,251	1,475	9.6
Jul	13.0	109,182	53,150	11,075	369	10.0
Aug	16.0	86,552	46,544	7,519	251	12.3
Sep	17.0	71,640	41,607	15,545	518	13.1
Oct	17.0	63,457	36,809	36,613	1,220	13.1
Nov	16.0	79,530	38,562	37,022	1,234	12.3
Dec	16.0	165,509	95,936	0	0	12.3

* WES model SALN = B1 * ln (LP1) + B2 * ln (PR2) + Int; (step backwards) Sta. 5 & 8; B1: -3.7513; B2: -.8975; Int: 64.3830; Sta. 4; B1: -7.5807; B2: 1.8062; Int: 76.4163

Table C7

Diversion Flows; Target Factor 0.77*

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity, ppt, Stations 5 and 8	4
Jan	16.0	297,662	131,967	0	0	11.1	11.6
Feb	14.0	505,680	147,868	6,868	229	9.1	8.8
Mar	9.5	592,720	169,911	70,653	2,355	7.3	6.3
Apr	8.0	465,300	127,950	124,945	4,165	6.2	4.7
May	8.0	312,790	90,328	0	0	6.2	4.7
Jun	12.5	125,340	51,273	114,808	3,827	8.2	7.5
Jul	13.0	109,182	53,150	0	0	10.0	10.1
Aug	16.0	86,552	46,544	21,830	728	11.2	11.7
Sep	17.0	71,640	41,607	24,523	817	13.1	14.4
Oct	17.0	63,457	36,809	63,729	2,124	13.1	14.4
Nov	16.0	79,530	38,562	28,220	941	12.3	13.3
Dec	16.0	165,509	95,936	0	0	12.3	13.3

* WES model SALN = B1 * ln (WT1 * LP1 + WT2 * LP2 + WT2 * PR1) + Int; (step forwards) WT1: 0.59; WT2: 0.42; WT3: 0.34 Sta. 5 & 8; B1: -4.6523; Int: 66.2685; Sta. 4; B1: -6.4650; Int: 88.2654

Table C8

Diversion Flows; Target Factor 0.50*

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity, ppt, Stations 5 and 8	4
Jan	16.0	297,662	131,967	206,128	6,871	9.6	9.6
Feb	14.0	505,680	147,868	257,407	8,580	7.0	5.9
Mar	9.5	592,720	169,911	301,356	10,045	4.8	2.8
Apr	8.0	465,300	127,950	369,768	12,326	4.0	1.7
May	8.0	312,790	90,328	54,131	1,804	4.0	1.7
Jun	12.5	125,340	51,273	417,156	13,905	6.3	4.9
Jul	13.0	109,182	53,150	16,617	554	6.5	5.2
Aug	16.0	86,552	46,544	272,557	9,085	8.0	7.3
Sep	17.0	71,640	41,607	108,596	3,620	8.5	8.0
Oct	17.0	63,457	36,809	285,842	9,528	8.5	8.0
Nov	16.0	79,530	38,562	152,067	5,069	8.0	7.3
Dec	16.0	165,509	95,936	0	0	8.0	7.3

* WES model (SALN = B1 * ln (WT1 * LP1 + WT2 * LP2 + WT2 * PR1) + Int; (step forwards)) WT1: 0.59; WT2: 0.42; WT3: 0.34; Sta. 5 & 8; B1: -4.6523; Int: 66.2685; Sta.4; B1: -6.4650; Int: 88.2654

Table C9

Diversion Flows; Target Factor 0.33*

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity, ppt, Stations 5 and 8	4
Jan	16.0	297,662	131,967	592,129	19,738	7.8	7.1
Feb	14.0	505,680	147,868	371,644	12,388	4.6	2.6
Mar	9.5	592,720	169,911	593,985	19,799	3.1	.5
Apr	8.0	465,300	127,950	535,406	17,847	2.6	-.2
May	8.0	312,790	90,328	329,340	10,978	2.6	-.2
Jun	12.5	125,340	51,273	612,531	20,418	4.1	1.9
Jul	13.0	109,182	53,150	247,827	8,261	4.3	2.1
Aug	16.0	86,552	46,544	468,483	15,616	5.3	3.5
Sep	17.0	71,640	41,607	329,639	10,988	5.6	4.0
Oct	17.0	63,457	36,809	498,780	16,626	5.6	4.0
Nov	16.0	79,530	38,562	370,774	12,359	5.3	3.5
Dec	16.0	165,509	95,936	0	0	5.3	3.5

* WES model SALN = B1 * ln (WT * LP1 + WT2 * LP1 + WT2 * PR1) = Int; (step forwards) WT1: 0.59; WT2: 0.42; WT3: 0.34; Sta. 5 & 8; B1: -4.6523; Int: 66.2685; Sta. 4; B1: -6.4650; Int: 88.2654.

Table C10

Diversion Flows; Target Factor 0.25*

Month	Salinity Target ppt	50% Monthly Flows cfs-days Pearl River	Lake Pontchartrain	Required Diversion cfs-days Monthly	Daily	Predicted Salinity, ppt, Stations 5 and 8	4
Jan	16.0	297,662	131,967	854,500	28,483	6.8	5.7
Feb	14.0	505,680	147,868	420,250	14,008	3.5	1.0
Mar	9.5	592,720	169,911	776,954	25,898	2.4	-.5
Apr	8.0	465,300	127,950	622,727	20,758	2.0	-1.0
May	8.0	312,790	90,328	524,273	17,476	2.0	-1.0
Jun	12.5	125,340	51,273	732,979	24,433	3.1	.5
Jul	13.0	109,182	53,150	426,986	14,233	3.3	.7
Aug	16.0	86,552	46,544	605,502	20,183	4.0	1.7
Sep	17.0	71,640	41,607	496,656	16,555	4.2	2.1
Oct	17.0	63,457	36,809	644,788	21,493	4.2	2.1
Nov	16.0	79,530	38,562	531,738	17,725	4.0	1.7
Dec	16.0	165,509	95,936	0	0	4.0	1.7

* WES model SALN = B1 * ln (WT1 * LP1 + WT2 * LP2 + WT2 * PR1) + Int; (step forwards) WT1: 0.59; WT2: 0.42; WT3: 0.34; Sta. 5 & 8; B1: -4.6523; Int: 66.2685; Sta.4; B1: -6.4650; Int: 88.2654.